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Western Regional Visibility Monitoring Teleradiometer and Camera Network

John Muir Inst. for Environmental Studies, Inc.
Napa, CA

Prepared for

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WESTERN REGIONAL VISIBILITY MONITORING:
Teleradiometer and Camera Network

by

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Cooperative Agreement #CR808562

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This report describes the western network and methods used to collect and process data, the results for the period of record and quality assurance procedures. A visibility theory section is provided to define terms and concepts. Seasonal and monthly mean standard visual range values with 90 percent confidence intervals and cumulative frequency plots for each monitoring location are reported. This report covers the data collection period from summer of 1978 through fall of 1981.

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INTRODUCTION

Since the 1950's there has been an increasing concern that the beauty of many of our nation's natural wonders is threatened by industrial development and population growth. Pollution from such sources as coal-fired powerplants began to reduce the visual clarity in many of these areas by the 1960's (EPA 1979). The increasing public concern resulted in specific visibility provisions being included in the Clean Air Act Amendment of 1977 (Public Law 95-95; August 7, 1977).

Provisions in the 1977 law deal with preventing of new visibility impairments in federal mandatory Class I areas (international parks, national wilderness areas, and national memorial parks exceeding 5,000 acres; and national parks exceeding 6,000 acres) and with remedying existing impairments in selected National Parks and National Wilderness Areas. The provisions provide a system to plan for and manage the use of the remaining air quality resource in areas of the country where air quality is better than National Secondary Ambient Air Quality Standards. In Class I areas safeguards are to be instituted to assure no air pollution damage to "air quality related values (including visibility)."

Data needs to meet these requirements include information about current conditions and possible visibility impairment by emissions from particular sources. This report describes research designed to assist the U.S. Environmental Protection Agency (EPA) and other federal and state agencies and operators of possible visibility impairing sources to address potential visibility problems in an expeditious and orderly way.

The report describes a western regional visibility monitoring network established by EPA in cooperation with the National Park Service to characterize visibility in representative Class I areas and to provide data that can be used to identify the sources of visibility impairment. Description of the methods used to collect and process the data, the monitoring locations, period of record, quality assurance procedures, and a descriptive summary of the data collected are included. A visibility theory section provides definitions of concepts and terms.

VISIBILITY THEORY

This section provides an overview of the physical processes which determine visibility. It is adapted from the EPA Interim Guidance for Visibility Monitoring (EPA 1980). Several references are available for those who wish to learn more about visibility theory (Middleton 1952; Malm 1979; Malm 1982; EPA 1979; and EPA 1980).

Visibility can be broadly defined as the degree of clearness of the atmosphere. Traditionally, visibility has been defined in terms of visual range--the distance from an object that corresponds to a minimum detected or threshold contrast between that object and its background. Threshold contrast refers to the smallest difference between two stimuli that the human eye can distinguish. The measurement of these quantities depends on the nature of the observer, this or her physical health, and mental attitudes of attention or distraction such as effects of boredom and fatigue.

Although visibility defined in terms of visual range is a reasonably precise definition, visibility is really more than being able to see a target at a distance for which the contrast is reduced to the threshold value. Visibility also includes seeing vistas at shorter distances and being able to appreciate the details of line, texture, color, and form. The definition of visibility and the selection of methods for monitoring visibility should relate to these different aspects of perceiving distant objects.

The importance of air quality impact on visibility, "the seeing" of distant objects, is based on the ability of aerosol and gases to scatter and absorb image-forming light as it passes through the atmosphere. The loss of image forming light is proportional to the sum of b_s (scattering coefficient) plus b_{abs} (absorption coefficients). The combined effects of scattering and absorption are referred to as extinction, represented by b_{ext} (extinction coefficient). Scattering by the gases which comprise unpolluted air is referred to as Rayleigh scattering. The Rayleigh scattering coefficient, $b_{Rayleigh}$, is dependent on air density. Figure 1 graphically displays the various elements of visibility, which are described in greater detail below.

Radiance, N, is a measure of the amount of monochromatic radiant energy present at some point in space. Thus, ${}_tN_r$, the apparent target radiance incident at an observation point located a distance r from some target, is a measure of radiant energy reaching an observer who is viewing a target in some specific direction. ${}_tN_r$ then is the sum of the attenuated inherent radiance of the target, ${}_tN_o$, and radiant energy scattered by the intervening atmosphere. The radiant energy scattered by the intervening atmosphere is a result of air molecules or aerosols scattering direct sun, diffuse light, or ground reflected light into the sight path. The volume scattering function determines how much of the radiant energy incident on the sightpath is scattered toward the eye. It is a minimum for radiant energy incident perpendicular to the sightpath and a maximum for radiant energy incident on the sight path in front of the observer (forward scattering).

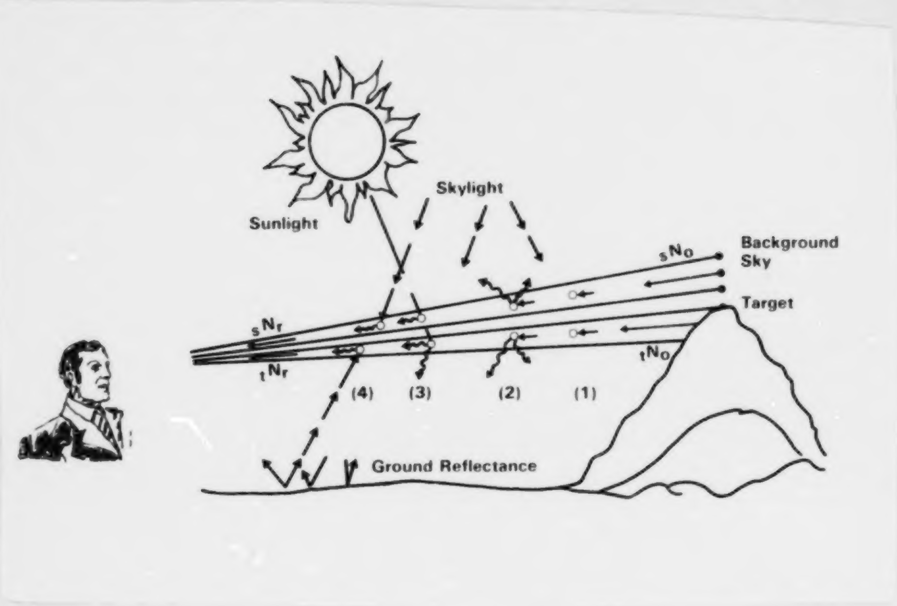
Skylight
Sunlight
$_sN_o$
Background Sky
Target
$_sN_r$
$_tN_r$
$_tN_o$
(4)
(3)
(2)
(1)
Ground Reflectance

Figure 1. Elements of visibility.

The observer is at a distance r from the target; the inherent background and target radiance are represented by $_bN_o$ and $_tN_o$ respectively while $_bN_r$ and $_tN_r$ are the apparent background and target radiances. Point (1) represents the reduction of sky and target radiance resulting from absorption; point (2) shows the reduction in sky and target radiance resulting from scattering; point (3) represents the increase in target and sky radiance resulting from sunlight scattered into the sight path; while point (4) represents increase in target and sky radiance due to scattering of sky light and ground reflected light.

Apparent target contrast, C_r, is defined as the difference between target radiance, ${}_tN_r$, and some background radiance, ${}_bN_r$ (when the background is the sky, ${}_bN_r$ becomes ${}_sN_r$), divided by the background radiance.

$$C_r = ({}_tN_r - {}_sN_r)/{}_sN_r. \quad (1)$$

In a similar manner, inherent contrast, C_o, is defined to be the contrast of a target viewed at a distance r=0, against a background sky:

$$C_o = ({}_tN_o - {}_sN_o)/{}_sN_o. \quad (2)$$

The ratio of the apparent to inherent contrast (C_r/C_o) is contrast transmittance, a measure of the ability of an intervening atmosphere to transmit contrast. The equation that describes the reduction of contrast over a path of length r is given by:

$$C_r = C_o({}_sN_o/{}_sN_r)\exp(-b_{ext}r) \quad (3)$$

The quantity ${}_sN_o/{}_sN_r$ is equal to 1 if the earth is assumed to be flat, the atmospheric aerosol and gas concentrations are assumed to be evenly dispersed both in the vertical and horizontal, and the observation angle is equal to zero (horizontal sight path). With these assumptions, equation (3) can be transformed to an equation for the extinction coefficient, b_{ext}:

$$b_{ext} = (-1/r)\ \ln(C_r/C_o). \quad (4)$$

In addition, if the above assumptions are met, visual range can be calculated from the extinction coefficient by:

$$V_r = 3.912/b_{ext}. \quad (5)$$

To account for the effect of air density at different elevations, we define standard visual range as:

$$SV_r = \frac{3.912}{b_{ext} - b_{Rayleigh} + 0.01}, \quad (6)$$

where the 0.01 is the reference Rayleigh scattering coefficient (km^{-1}) corresponding to a reference altitude of 1.55 km above sea level.

MEASUREMENT METHODOLOGY

A contrast measurement technique, using teleradiometers, was chosen to measure visibility. These instruments measure the amount of radiant energy reaching a detector from selected viewing targets and their surrounding background. Teleradiometers directly measure the apparent spectral radiance of the sky, target or a plume and thus allow for a calculation of target or plume contrast and its change. The apparent contrast of targets (or plumes) can be easily calculated from the measurements using equation 1 or 3. Visual range can also be calculated after making a series of assumptions about the inherent contrast of the target, uniformity of the atmosphere along the sight path, and angle of observation.

Teleradiometers make measurements in a way that is very similar to observations made by the human eye. In Figure 1, the eye could be replaced by a teleradiometer. Properties of the target, air quality (homogeneity and concentration of visibility reducing substances), distance to the target, illumination of the sight path, humidity, and observation angle all affect the measurement.

Photography was also employed at many of the network sites to provide a means to qualitatively document changing visual air quality on various vistas. This is particularly important where plumes or layered haze are a concern since the teleradiometer would not necessarily provide a measure of these conditions.

MANUAL TELERADIOMETER

The manual teleradiometer consists of a 0.5-meter focal length objective lens, filter turret, beam diverter, flip mirror, eye piece, photodiode, and an electrical system consisting of batteries, switches, a liquid crystal display, and various electronic components. The photodiode provides the interface between the optical and electrical systems by producing an electrical current proportional to the amount of radiant energy which strikes its surface. The unit is portable (weighing 3.2 kilograms), battery powered, and manually operated. A tripod or more permanent mounting device is required to steady the teleradiometer during measurements. The teleradiometer has been designed for ease of operation and can be readily dismantled. Figure 2 shows a manual teleradiometer, and Figure 3 is a diagram of the associated optical system. A brief discussion of the various system components is given below, followed by a discussion of the operation of the instrument.

Instrument Description

The telescope lens has a nominal diameter of 54 mm with a clear aperture of 47.5 mm and a focal length of 508 mm. The lens is a cemented and coated achromat. The lens can be removed easily for cleaning and can be adjusted to focus the target image. The filters are mounted in a five-position filter

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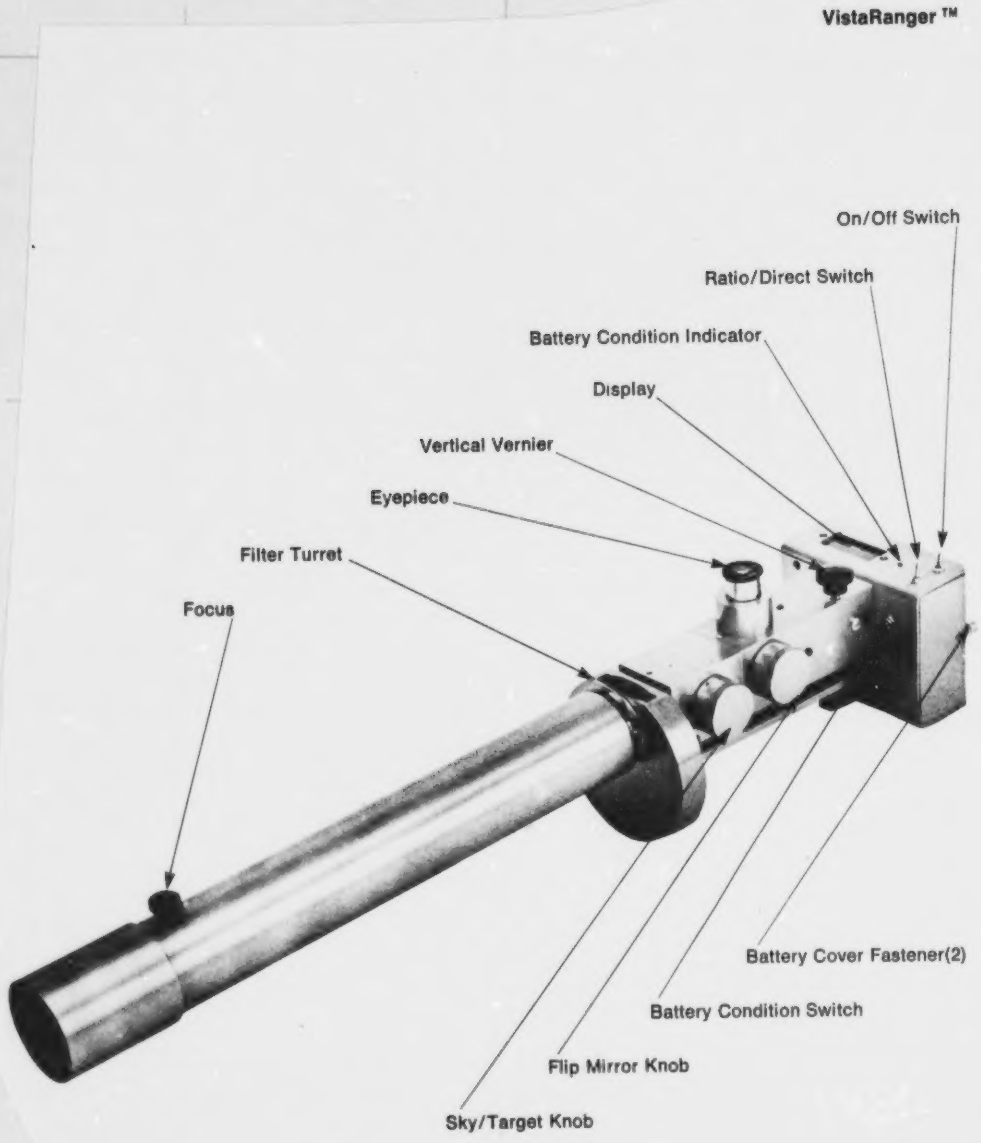
VistaRanger ™
On/Off Switch
Ratio/Direct Switch
Battery Condition Indicator
Display
Vertical Vernier
Eyepiece
Filter Turret
Focus
Battery Cover Fastener(2)
Battery Condition Switch
Flip Mirror Knob
Sky/Target Knob

Figure 2. Manual Teleradiometer.

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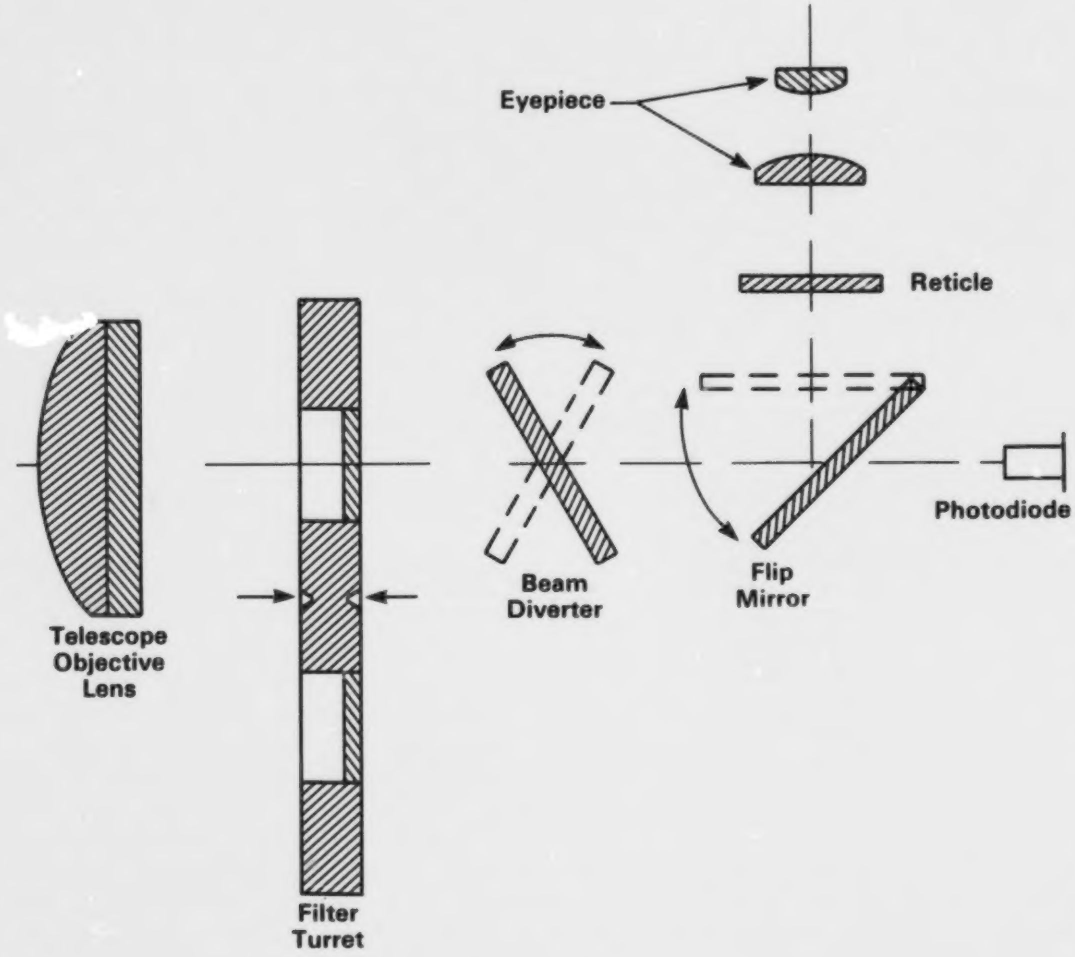

Eyepiece
Reticle
Telescope Objective Lens
Filter Turret
Beam Diverter
Flip Mirror
Photodiode

Figure 3. Manual Teleradiometer Optics (based on Model 3010 VistaRanger™ Optics).

turret and correspond to wavelengths of 405, 450, 550, and 630 nm. One filter, centered in the green (550 nm), is coincident with the wavelength of maximum response for the human eye. The turret is also fitted with a clear glass piece which is used to align the instrument on the target. The filter turret is located between the telescope lens barrel and the main instrument assembly and is held stationary by two hex screws (see Figure 2). The turret can be removed easily by the operator for routine cleaning of the filters, or, if necessary, for repairs.

The beam diverter is a disk of clear acrylic which, when rotated from the sky to target position, causes the target image to be displaced (in the vertical direction) by 3.0 mm. This makes it possible for the single photodiode to measure both the sky and target apparent spectral radiance without moving the instrument (see Figure 3). A manually operated flip mirror allows the operator to direct the target image to either the eyepiece for viewing, or to the photodiode for measurements. A knob on a threaded screw is provided to allow a fine adjustment of the instrument elevation angle. While the tripod is used for coarse adjustment of the azimuth and elevation angles, this screw adjustment provides a fine control for the elevation setting and aids in sighting the target.

The eyepiece has a reticle to aid in the alignment of the teleradiometer. A horizontal horizon line in the middle of the field of view is typically placed on the peak of the target of interest. There is a small circle above the line and another directly below it on the other side of the line, with identical distance between each circle and the line. The circles show the portion of the view to be focused on the photodiode when the beam diverter is turned to sky or target position. The eyepiece is also provided with a lens cap in order to prevent stray light from hitting the photodiode. Stray light will affect the readings by decreasing the apparent contrast and visual range. Figure 4 shows an illustration of the eyepiece reticle. The photodetector is a single, blue-enhanced, PIN silicon photodiode.

A key component in the teleradiometer is the analog to digital converter with a 2 volt liquid crystal display (LCD). This display reads out voltage in millivolts up to a maximum of 1999. Though the display has four place precision, the rightmost digit is rounded off by the operator so that the recorded numbers do not misrepresent the precision actually achievable by the teleradiometer.

As with most battery operated instruments, insufficient battery voltage is the most common cause of failure. Early model teleradiometers are equipped with three 9-volt alkaline batteries. One battery supplies the very low power needed by the LCD while the other two operate the main circuitry. The latter two batteries must each have at least 7.0 volts for proper operation of the teleradiometer. For this reason, each instrument has been equipped with a battery test circuit incorporating a light emitting diode (LED) and a test switch. Upon activating the switch, the LED will light only if the battery voltage exceeds 7.0 volts. In newer models the LED test circuit has been eliminated. When the battery voltage drops below 7.0 volts, a low battery signal is displayed on the LCD.

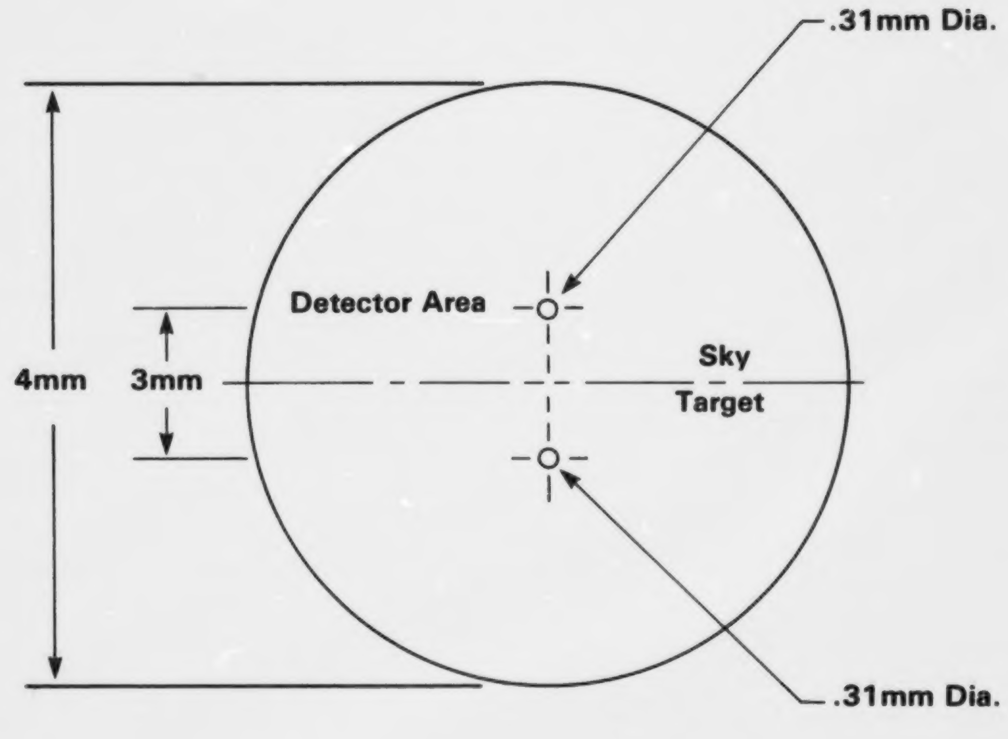

.31mm Dia.
Detector Area
4mm
3mm
Sky
Target
.31mm Dia.

Figure 4. Manual Teleradiometer Eyepiece Reticle (Model 3010 VistaRanger™).

The instrument has an on/off switch, a Direct (D)/Ratio (R) switch, and, in older models, a battery test switch. In the direct mode, the LCD will display a voltage proportional to either the sky or target apparent spectral radiance. In the ratio mode, the LCD will display a voltage proportional to the ratio of target to sky apparent spectral radiance.

Operation

The procedure used to make contrast measurements with the manual teleradiometer consists of five steps: set up, target sighting, measurement, data recording and a recheck of target sighting.

The teleradiometer is positioned in the same location for each series of measurements. The instrument is switched on and allowed to warm up for a brief period of time. The battery integrity is checked prior to the measurement process.

The reticle in the eyepiece aids aiming by providing a horizon line, a small target circle beneath it and a small sky circle directly above it (see Figure 4). The observer usually puts the horizon line on the peak of the mountain and the target circle on the target area. The target is usually chosen to be a patch of coniferous trees so it will be green throughout the year. The horizon line need not be exactly on the top of the mountain peak. The important requirement is that the sky circle must be completely filled with sky when the target circle is completely filled with target. The aiming procedure is done with the beam diverter knob in the sky position and the filter turret set on C (clear glass). Small adjustments in the azimuth and elevation angles are made to put the target circle on the particular patch of trees with the least amount of rocks appearing between the trees. A vernier adjustment has been provided to aid in the elevation adjustment.

If necessary, the instrument is focused by loosening the lens adjusting screw, sliding the lens in or out until the image focuses, and then tightening the adjusting screw.

The instrument is designed to make the fewest possible measurements necessary to compute visibility related variables. In ratio mode, the electronics are designed to measure and store the apparent spectral radiance of the sky as a voltage and divide it into the target apparent spectral radiance. The output to the liquid crystal display is the ratio. After reading the ratio, the apparent spectral radiance of the target is measured. This is done by switching the Ratio/Direct switch to Direct.

A final check to ensure that the teleradiometer is still properly aligned on the target is done immediately after taking the measurements. This is done by rotating the filter turret to C (clear glass) with the beam diverter in the sky position and viewing the target through the eyepiece. If the target circle (Figure 4) is not on the target, then the teleradiometer is realigned and the measurements repeated.

A data sheet is used to record every measurement. Each data sheet is identified by a unique location code, month and day. The operators are encouraged to write notes on the record sheet, indicating any problems or special observations. In addition to the ratio and target direct readings, meteorology, sun and snow codes are recorded for each target.

Meteorological and Sun/Snow Codes

The view of a distant target depends on the contrast of the target against its surroundings. The contrast depends on the light reflecting characteristics of the target, the illumination of the target and the sight path, and the optical characteristics of the air along the sight path. To help specify these conditions, a meteorological code and sun/snow was assigned to each target for each measurement. The codes are included on the data sheet.

The meteorological code serves two functions. It describes the cloudiness of the sight path, and it describes certain situations when measurements are not made. Meteorological code 0 denotes a cloud-free sky, which provides the simplest illumination of the target and atmosphere. Meteorological code 1 denotes a cloud-free observation plane defined by the target, observer, and sun. This case is still relatively simple optically, because there are no clouds in the plane that can cause non-uniform illumination of the sight path or target. Clouds can be present elsewhere in the sky for this code but they have less effect on the illumination of the sightpath. Meteorological codes 2, 3, and 4 denote some clouds in the observation plane. Code 2 is for clouds covering up to one-third of the sky; code 3 is for one-third to two-thirds cloud cover; and code 4 is for more than two-thirds cover. Meteorological code 5 is for a completely overcast sky. Readings recorded for meteorological codes 0 through 5 can be analyzed for various amounts of clouds.

Higher numbers of the code do not have accompanying readings. Code 6 means it was raining on the teleradiometer site. The observers are instructed not to take readings in the rain, a precaution that helps protect the teleradiometers from water damage. Code 7 means the readings were not taken because of some reason not related to the atmosphere. For example, the observer may have been called to help in an emergency. If measurements cannot be taken due to the sun shining into the lens, then the observer records code 8. If sunlight directly strikes the lens, then the refracted light may strike the photodiode and change the reading. Operators may fabricate an extension for the sunshade on the teleradiometer in order to make an otherwise disallowed reading.

Each meteorological code is paired with a sun/snow code. The sun/snow code describes the relative amount of snow on the target and the lighting conditions on the target at the time of the measurements. Snow greatly increases the reflectance of light from the target towards the observer and from the ground to the sight path. While the meteorological code describes the conditions relative to the entire sky, the sun/snow code describes conditions relative to the individual targets. In most cases, the meteorological code will be the same for all targets, whereas the sun/snow code will probably vary. It should be noted that an important variation on the situation exists when the target cannot be seen. If it is obscured by air pollution rather than clouds, then the regular meteorological code should be recorded as determined by cloud cover. Instead of regular readings though, -1 is recorded for each of the four ratios and each of the four target radiances.

The meteorological and sun/snow codes are summarized in Figures 5 and 6. Figure 7 summarizes the measurement and data recording process using a flow diagram. By following the logic shown in the diagram, the proper codes can be accurately assigned to the data. Prior to October 1, 1980, a similar though less complex code system was used (see Table 1).

CAMERA SYSTEM

In order to photo document vista appearance and weather conditions, color photographs were taken of selected targets. The photographs were taken twice a day during the morning and afternoon manual teleradiometer measurements.

The Olympus OM-2 35-mm SLR automatic camera, equipped with a 135-mm telephoto lens and a haze filter, is used in the network. Kodachrome ASA 25 color slide film is used at all locations for consistency. This film was chosen because it was reputed to give the best representation of true color.

Loading Film

A fresh roll of film is loaded into the camera following the manufacturer's instructions. The roll number, date and location are recorded on a log sheet. The automatic flash is installed and the camera is set on auto mode. A gray scale and color chart are photographed.

Operation

The camera is set on automatic with an aperature setting of f/4. For most daylight conditions, this setting produces a good photograph. The camera automatically adjusts the shutter speed. If the camera is equipped with a data back, the date and time display are checked and adjusted if necessary. The target is sighted through the viewfinder. For most targets, the focus setting will be infinity. The photograph is taken and the exposure, date, time, target number and/or name and any notes or comments about the photograph are recorded on the log sheet.

QUALITY ASSURANCE

To prevent loss of valuable data due to instrument malfunction or "out of control situations," a strong quality control effort is necessary. The quality control program consists of four tasks:

1. regular preventive maintenance and operational checks;
2. frequent functional checks of all instrumentation;
3. data quality checks; and
4. documentation

METEOROLOGICAL CODES

Code	Condition
0	Total sky cloudless
1	No clouds in sun-target-observer plane
2	Less than 1/3 cloud cover, total sky
3	1/3 to 2/3 cloud cover, total sky
4	2/3 to total cloud cover
5	Overcast
6	Raining on site
7	Readings not taken - unrelated to atmospheric conditions
8	Sun in lens, readings not taken

MET CODES

Code 0

This code is fairly obvious. The only problem may occur when there are very faint high wispy clouds. As in all cases, use your own discretion.

Code 1

This code often causes problems. If the met code for most of your targets is a 2, 3, or 4, that is there are clouds in the sky, it is still possible to have a target with no clouds in the target-sun-observer plane. That target would receive a 1.

Code 2, 3, 4

These codes are not to be used independently for each target because of the total sky concept. If less than 1/3 of the total sky is covered, then the met code is the same for all targets. Two exceptions to this are:

> Code 1 - even though 1/3 of the sky is covered, this particular target has no clouds in the target-sun-observer plane.
>
> Sun/snow code 9 - target obscured by clouds, met code remains the same, sun/snow code becomes 9.

Code 5

Overcast; total sky is cloud covered.

Code 6

Raining on the observation site, readings not taken.

Code 7

Readings not taken for reason not relating to the atmosphere. It helps to write the reason down that day, as it is often hard to remember later.

Code 8

If you are unsure about sun hitting the front lens, set the telephotometer to take a direct reading of the target, then shade the end of the telescope with your hand. If the direct reading drops appreciably, then this target should receive a code 8, or the telephotometer should be fitted with a sun shade.

Figure 5. Meteorological code instructions used by teleradiometer operators.

SUN/SNOW CODE

CODE	TARGET IN SUN	CLOUD BEHIND TARGET	SNOW ON TARGET
1	YES	YES	YES
2	YES	YES	NO
3	YES	NO	YES
4	YES	NO	NO
5	NO	YES	YES
6	NO	YES	NO
7	NO	NO	YES
8	NO	NO	NO
9	Target obscured by clouds		

This code is most useful in data interpretation for close or intermediate targets. For these, you should be able to make accurate estimates.

1. Make determinations of these codes by utilizing both direct and telephotometer observation.

2. The area of the target within and around the detector circle should be considered. If most of the mountain is in the sun but the detector circle is in shade, then the target would be considered to be in the shade. If there are no clouds behind most of the mountain, but there is a cloud in the detector area, then the target is considered to have a cloud background.

3. If there happens to be a large snow bank or shade patch that is half in your detector area, feel free to move the detector slightly to an area of more uniform density. This also stops very jumpy readings caused when the detector alternately hits light and dark patches due to wind.

4. When using the sun/snow codes, don't worry about being mistaken on very distant targets. If you are in doubt about whether the target is in the sun or shade, and it's hard to estimate from the cloud cover, assume that the target is in the sun.

   If in doubt about whether or not there are clouds behind the target, assume there are no clouds.

5. In distinguishing between a partially snow covered and a covered classification, an estimate must be made as to the dominant effect on reflected light. A new snow on the target would obviously warrant a covered classification. There comes a time, however, when the trees and shrubs become more dominant in the view. Once again it is a subjective judgement and you can only do your best.

Figure 6. Sun/snow code instructions used by teleradiometer operators.

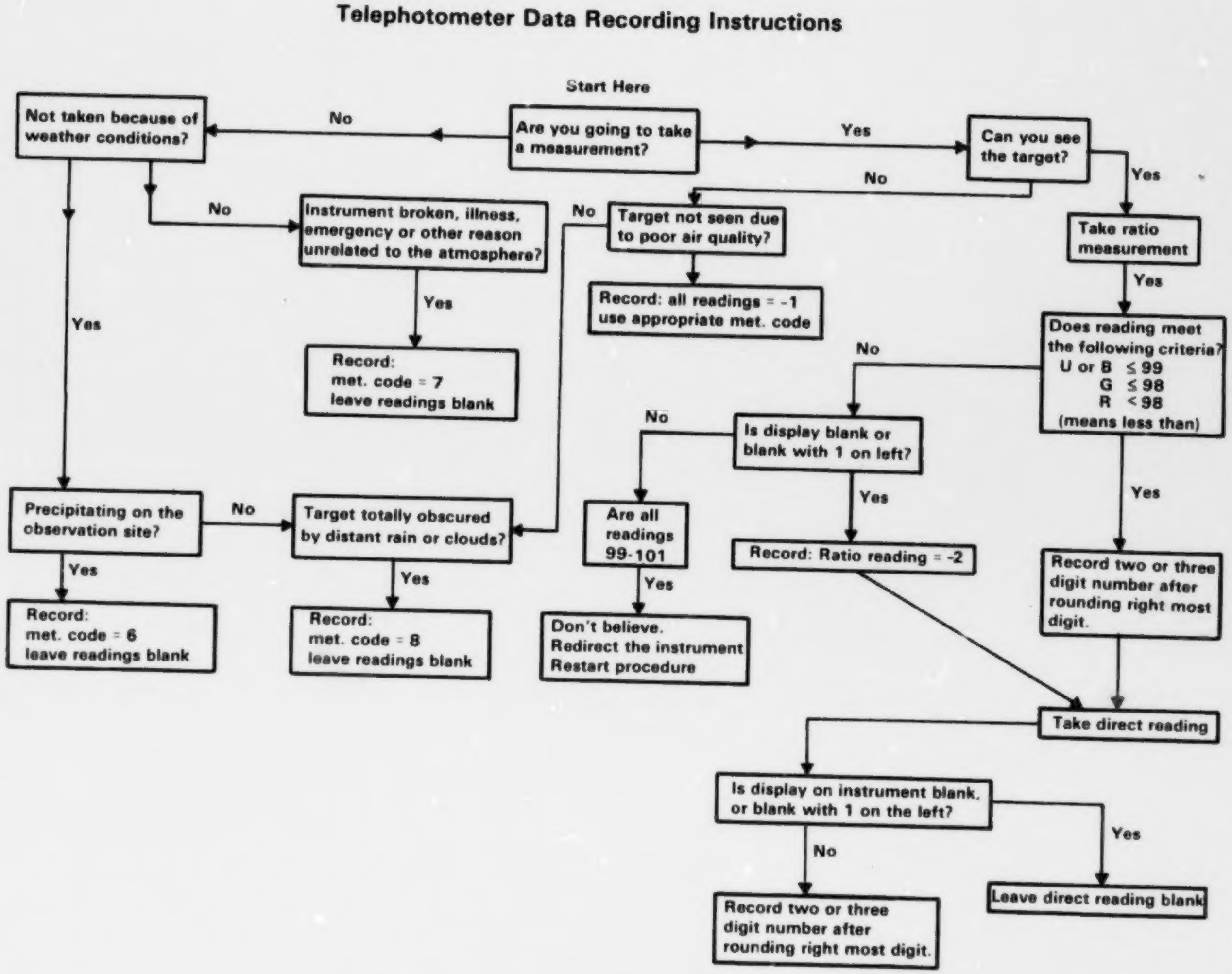

Telephotometer Data Recording Instructions
Start Here
Are you going to take a measurement?
No
Yes
Not taken because of weather conditions?
Can you see the target?
No
Yes
No
Instrument broken, illness, emergency or other reason unrelated to the atmosphere?
No
Target not seen due to poor air quality?
Take ratio measurement
Yes
Yes
Record: all readings = -1 use appropriate met. code
Yes
Record: met. code = 7 leave readings blank
No
Does reading meet the following criteria? U or B ≤ 99 G ≤ 98 R < 98 (means less than)
No
Is display blank or blank with 1 on left?
Yes
Yes
Precipitating on the observation site?
No
Target totally obscured by distant rain or clouds?
Are all readings 99-101
Record: Ratio reading = -2
Record two or three digit number after rounding right most digit.
Yes
Yes
Yes
Record: met. code = 6 leave readings blank
Record: met. code = 8 leave readings blank
Don't believe. Redirect the instrument Restart procedure
Take direct reading
Is display on instrument blank, or blank with 1 on the left?
Yes
No
Leave direct reading blank
Record two or three digit number after rounding right most digit.

Figure 7. Data recording instructions used by teleradiomater operators.

TABLE 1. METEOROLOGICAL AND SNOW CODES (used before 10-1-80)

Meteorological Code	Condition
0	Cloudless sky
1	No clouds in plane of sun, target and observer
2	Total sky is less than 1/3 cloud covered
3	Total sky is 1/3 to 2/3 cloud covered
4	Total sky is more than 2/3 cloud covered
5	Overcast sky

Snow Code	Condition
1	No snow on target; no snow on ground
2	Covered target; covered ground
3	Covered target; partially covered ground
4	Covered target; no snow on ground
5	Partially covered target; any condition on ground
6	No snow on target; any condition on ground

Preventive Maintenance

Tables 2 and 3 summarize the various types of maintenance which are performed. Most of the tasks are done on a weekly basis, although some items are done only as needed.

Functional Checks

Functional checks are performed less frequently than the preventive maintenance tasks. The checks discussed in this section are performed monthly.

The photodetector must be aligned with the optical system so that only light from the target area is measured. The detector must be aligned in both the horizontal and vertical planes; otherwise, it will respond to light received from some area in the field of view other than the desired target area. The optical alignment check is designed to verify that the target as viewed through the eyepiece is the same as that seen by the photodetector.

The optical alignment check is performed using a target consisting of a black background with a white dot and two white lines or stripes, one horizontal and one vertical, and each approximately 1 cm across. On the opposite side are two white lines forming crosshairs. Figure 8 shows a simple diagram of the optical alignment target. Basically the test consists of horizontal and vertical scanning of the alignment target with the teleradiometer in an effort to find the orientation with greatest signal. That orientation should correspond to a white portion of the target aligned with the proper eyepiece reticle.

Data Quality Check

The data sheets are reviewed for errors by field personnel. The sheets are checked to ensure that:

1. the meteorological and sun/snow codes have been assigned to each target correctly;
2. the contrast readings have been entered on the data sheet correctly, e.g., all two-digit values have been entered right-justified;
3. the data sheets contain the location, date, and operator's initials;
4. any missing data are accounted for either through the appropriate meteorological code or a notation by the operator indicating why the readings were not taken; and
5. the readings are consistent. Experience will indicate when certain values seem inconsistent with past readings for a given target.

Documentation

Results of all preventive maintenance tasks, functional checks, or anything that could affect data quality are documented. Standard procedures for

TABLE 2. CONTRAST TELERADIOMETER MAINTENANCE

Item	Maintenance Action Examine	Clean	Replace	Frequency	Remarks
Batteries	x			Before each series of measurements	Check voltage; if less than 7.0 volts, replace.
			x	Once per quarter	
Optics (lens, filters, etc.)	x	x		Once per week	Use soft tissue. Do not use concentrated solvents or abrasives.
Mount (tripod)	x	x		As required	Tighten all screws, nuts, etc. Lubricate necessary parts.

TABLE 3. CAMERA SYSTEM MAINTENANCE

Item	Maintenance Action Examine	 Clean	 Replace	Frequency	Remarks
Lens		x		Once per week	Lens should be inspected for chips, tightness, etc.
Batteries light meter	x			Once per week	Battery voltage should be checked using either external voltmeter or internal check.
			x	As required	
Auto winder*	x			Once per week	Operator should check battery voltage at least once per week.
			x	As required	
Tripod*	x			Once per week	Camera mount should be checked to verify that all parts are tight.
			x	As required	
Timer*	x			Once per week	Timer connections to data recording system and camera must be securely fastened.

* For sites with automated camera systems.

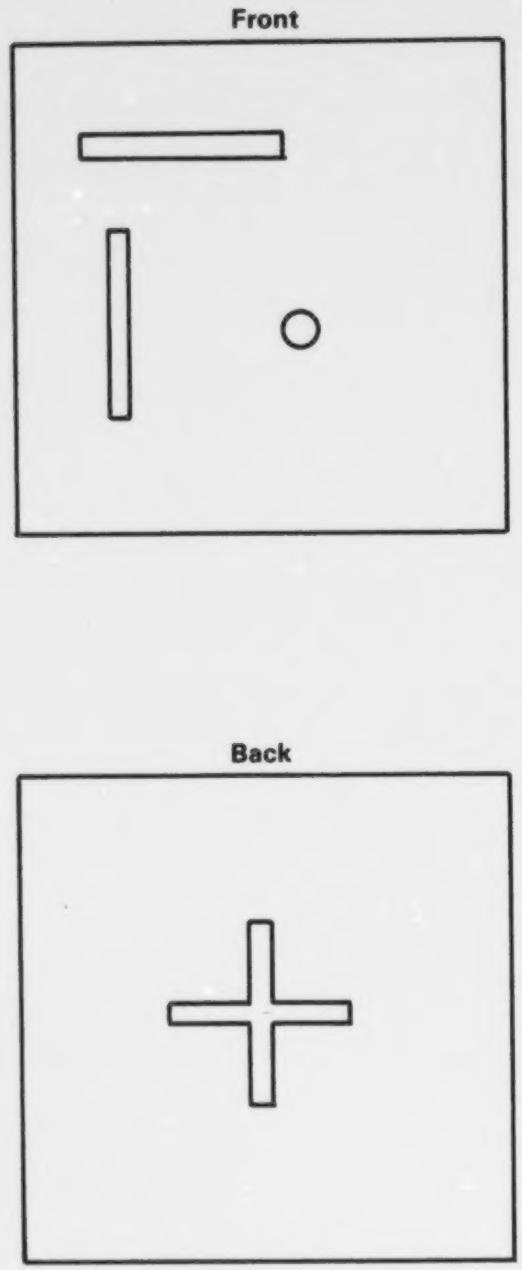


Figure 8. Optical alignment target.

equipment operation, maintenance, quality control and data handling are documented in a procedures manual. The data are maintained on original data sheets, computer cards and magnetic tapes. Data are periodically reproduced with copies stored in different locations to reduce the chance of loss by damage to the principal data library.

NETWORK DESCRIPTION

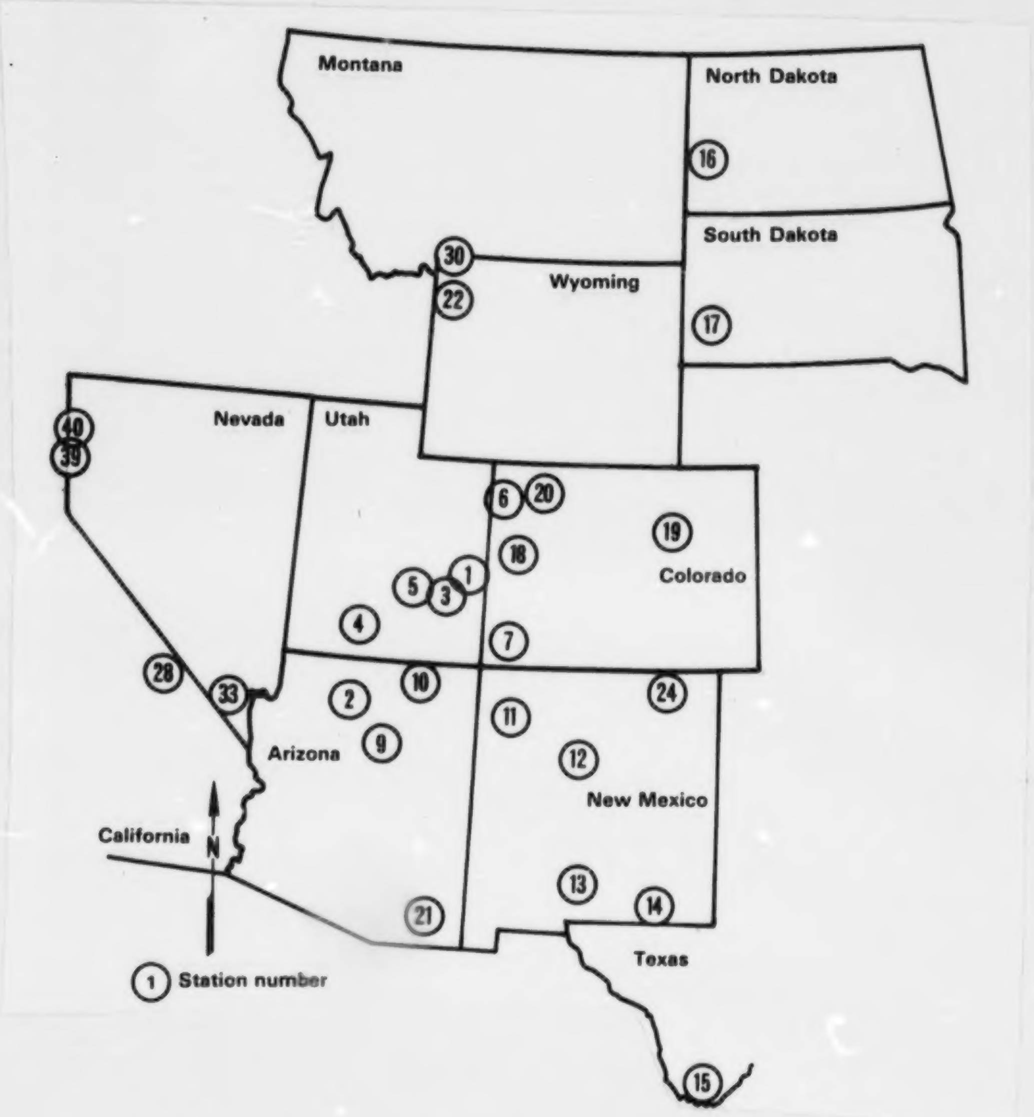
TELERADIOMETER NETWORK

Manually operated teleradiometers were installed in 16 National Park Service Class I areas, 10 sites of mandatory Class II status (national monuments, national primitive areas, national preserves, national recreation areas, national wild and scenic rivers, national wildlife refuges, or national lakeshores or seashores of 10,000 or more acres) and two sites at Lake Tahoe that adjoin National Forest Service Class I areas. Figure 9 shows the western regional observation site locations (excluding Olympic, WA, Shenandoah, VA, and Acadia, ME). The monitoring has been continuous since its initiation. For most sites, monitoring began in the summer of 1978. At all but one site, measurements were made three times daily at 9 a.m., 12 noon, and 3 p.m. local time. The 12 noon measurement was not performed at Chaco Canyon.

The observation site at each park or monument was chosen to provide a variety of vistas toward distant targets. Up to six targets in a variety of directions were selected at each observation site. The targets were selected, where possible, at distances between 10 and 75 percent of the estimated average visual range, as recommended in the Interim Guidance for Visibility Monitoring (EPA 1980). Within these distances, apparent contrast is most sensitive to changes in airborne fine particulate concentration (Malm 1979).

To provide a more reliable data base, desirable target characteristics included a distinctive shape for easy aiming of the teleradiometer at the target, a low elevation angle of observation, and a dense cover of evergreen vegetation. However, rock targets were also selected to provide a greater variety of situations for future investigations of apparent color changes with visibility degradation. Table 4 lists the specifications for each target. As seen in Table 4, some target changes were made at Grand Canyon and Bryce Canyon National Parks.

The computation of standard visual range requires knowledge of the inherent spectral contrast, C_o of the targets. This was measured in a series of field experiments, using different vegetation types under varying illumination. The measured inherent spectral contrasts shown in Table 5 were used to determine the proper values for each target at each of the three times of day. These measurements indicated that evergreen vegetation was a satisfactorily dark target in direct sun or shade, but rock targets in direct sun had varying and unpredictable inherent spectral contrasts. Therefore, computations requiring C_o were not made for rock targets. Similarly, targets covered with deciduous vegetation were not used in autumn and winter when the leaves change color. The direction to the target from the measurement location was used to estimate the direction of sunlight on the target and the inherent spectral contrast of each target at each measurement time.


Montana
North Dakota
South Dakota
Wyoming
Nevada
Utah
Colorado
Arizona
New Mexico
California
Texas
N
16
30
22
17
40
39
6
20
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18
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28
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9
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24
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14
21
15
1 Station number

Figure 9. Regional visibility monitoring network teleradiometer locations.

TABLE 4. SITE/TARGET INFORMATION

Location Number	Location Name	Target Number	Name	Lat (°N)	Long (°W)	Distance (km)	Azimuth Angle (°)	Elevation (feet)	Elevation Angle (°)	Target Cover	Calculate SV_r[a]
1	Canyonlands National Park		Island in the Sky	38°27'	109°45'	0	---	5,940	----	---	
		1	South Mountain	38°23'	109°16'	50	105	9,600	1.3	vegetation	yes
		2	Patmos Mountain	38°41'	110°02'	76	345	6,200	0.06	1/2 rock	no
		3	Old Woman Plateau	38°41'	110°38'	141	292	8,600	0.33	rock and pj[b]	no
		4	Thousand L. Mountain	38°25'	111°28'	144	270	9,900	0.48	vegetation	yes
		5	Mt. Ellen	38°07'	110°48'	94	246	10,600	0.87	vegetation	yes
2	Grand Canyon National Park		Hopi Fire Tower	36°4'	112°10'	0	---	7,090	---	---	
		1	Shiva Saddle	36°11'	112°8'	16	6	7,750	0.72	vegetation	yes
		2	Trumbull Mountain	36°24'	113°7'	96	293	8,030	0.17	7/8 vegetation(pj)	yes
		3	Red Butte	35°50'	112°6'	28	170	7,324	0.02	vegetation	yes
	(before 10 May 1979)	4	Humphrey	35°21'	111°41'	91	151	11,790	0.90	dark rock	yes
	(after 9 May 1979)	4	Kendrick	35°24'	111°53'	76.5	163	9,685	0.59	vegetation	yes
		5	Desert View Point	36°3'	111°51'	30	96	7,470	0.22	vegetation, rock	yes
3	Canyonlands National Park		Hans Flat	38°19'	110°11'	0	---	6,500	---	---	
		1	Mt. Holmes	37°48'	110°35'	62	215	7,600	0.31	1/4 vegetation	yes
		2	Mt. Ellen Flank	38°10'	110°48'	57	261	8,000	0.46	1/2 vegetation	yes
		3	San Rafael Swell	38°38'	110°43'	67	322	6,500	0.00	rocks	no
		4	Book Cliffs	39°07'	110°03'	88	8	6,000	-0.10	pink rock	no
		5	Abajos	37°51'	109°30'	72	130	10,000	0.85	vegetation	yes
4	Bryce Canyon National Park		Bryce Point	37°36'	112°10'	0	---	8,300	---	---	
		1	Navajo Mountain	37°03'	110°54'	130	120	9,100	0.11	vegetation	yes
		2	Table Cliffs	37°40'	111°54'	26	76	10,000	1.14	rock	no
	(after 9 June 1979)	3	Table Cliffs Plateau	37°42'	111°54'	27	68	10,000	1.10	vegetation	yes
		4	Parker Mountain	38°14'	111°55'	67	20	9,400	0.29	vegetation	yes
		5	Cottonwood Peak	37°56'	112°39'	57	311	7,600	-0.21	vegetation	yes
5	Capitol Reef National Park		Panorama Point	39°18'	111°20'	0	---	6,170	---	---	
		1	Capitol Gorge	38°07'	111°11'	19	146	6,500	0.30	red rock	no
		2	Mt. Pennell	37°58'	110°48'	60	130	10,100	1.14	sub alpine, fir	yes
		3	Ant Hill	38°21'	111°29'	17	283	8,700	2.60	pj	yes
		4	Teasdale Bench	38°19'	111°29.5'	17	275	7,900	1.78	rock	no
		5	Repeater Hill	38°17'	111°30.5'	19.5	263	8,260	1.87	3/4 pj	yes
6	Dinosaur National Monument		Scenic Overlook	40°17'	109°00'	0	---	6,790	---	---	
		1	Uintas, UT	40°33'	110°24'	150	283	11,100	0.50	vegetation	yes
		2	Book Cliffs, UT	39°41'	110°25'	141	243	8,000	0.15	colored	no
		3	Rabbit Mountain, CO	39°53'	108°59'	45	186	7,000	0.08	vegetation	yes
		4	Book Cliffs, CO	39°36'	108°58'	76	180	7,500	0.16	vegetation	yes
		5	Cathedral Bluffs, CO	40°08'	108°32'	42	132	8,000	0.50	vegetation	yes

(continued)

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[a] - SV_r = standard visual range

[b] - pj = pinion juniper

TABLE 4. (Continued)

Location Number	Location Name	Target Number	Name	Lat (°N)	Long (°W)	Distance (km)	Azimuth Angle (°)	Elevation (feet)	Elevation Angle (°)	Target Cover	Calculate SV_r
7	Mesa Verde National Park		Far View Visitor Ctr.	37°16'	108°29'	0	---	8,000	----	---	
		1	Lukuchukai Mts 1	36°28'	109°00'	106	220	8,500	0.08	1/2 - 3/4 pj	yes
		2	Lukuchukai Mts 2	36°12'	108°52'	130	194	9,000	0.14	1/2 pj	yes
		3	Hogback	36°38'	108°34'	70	185	6,060	-0.48	rock	no
		4	Chaco River Rise	36°40'	108°29'	109	178	7,200	-0.13	3/4 vegetation	no
		5	Bridge Timber Mt.	37°10'	108°57'	47	100	8,400	0.14	vegetation	yes
8	Olympic National Park		Scenic Turnout	48°01'	123°23'	0	---	2,050	---	---	
		1	Sequim Hill	48°02'	123°06'	19	88	2,450	0.37	pines	yes
		2	Mt. Baker Flank	48°43'	122°04'	118	52	4,500	0.36	pines	yes
		3	Parliment Hill	48°40'	122°49'	93	29	2,300	0.05	pines	yes
		4	Empress Mountain	48°27'	123°39'	53	336	2,100	0.02	pines	yes
		5	Gowlland Range[c]	48°30'	123°30'	52	357	1,350	-0.10	pines	no
9	Wupatki National Monument		Vis. Ctr. Cinderhill	35°30'	111°20'	0	---	5,220	---	---	
		1	White Horse Hills	35°24'	111°42'	34	247	8,800	1.84	vegetation	yes
		2	Flank of Humphrey	35°22'	111°38'	33	239	10,600	2.84	vegetation	yes
		3	Top of Humphrey	35°21'	111°41'	34	236	12,350	3.66	vegetation	yes
		4	No Name Crater	35°20'	111°17'	21	158	6,380	0.96	1/3 vegetation	no
		5	Montezumas Chair	35°27'	110°30'	79	96	3,940	-0.28	rock	no
10	Navajo National Monument		Water Tower	36°41'	110°33'	0	---	7,350	---	---	
		1	Navajo Mountain	36°02'	110°52'	48	325	9,000	0.60	1/2 limestone and vegetation	yes
		2	Square Butte	36°37'	110°57'	36	260	7,800	0.22	all red rock	no
		3	Black Mesa 1	36°24'	110°48'	40	217	6,800	-0.24	pj	yes
		4	Black Mesa 2	36°40'	110°22'	16	96	8,000	0.71	pj	yes
		5	Tsegi Canyon Wall	36°43'	110°28.5'	3.3	66	7,700	1.85	pinion, juniper	no
11	Chaco Canyon National Monument		Pueblo Alta Ruins	36°04'	107°57'	0	---	6,430	---	---	
		1	Beautiful Mountain	36°28'	109°00'	105	297	9,400	0.49	vegetation	yes
		2	Washington Pass	36°06'	108°52'	94	270	8,700	0.42	vegetation	yes
		3	Small Butte	35°41'	108°15'	54	210	7,970	0.50	1/2 vegetation	no
		4	Hosta Butte	35°37'	108°12'	50	202	8,600	0.76	1/2 vegetation	no
		5	Mt. Taylor	35°14'	107°35'	97	162	11,400	0.89	vegetation	yes
		6	Naciniento Mountains	36°05'	016°52'	99	90	10,200	0.66	vegetation	yes
12	Bandelier National Monument		Rim Fire Tower	35°47'	106°16'	0	---	6,560	---	---	
		1	Caballo Mountain 1	35°57'	106°20.5'	21	336	9,300	2.32	grassy	no
		2	Caballo Mountain 2	35°57'	106°21'	21	334	9,300	2.32	forest	yes
		3	Tecolote Peak	35°14'	106°22'	65	190	8,200	0.44	vegetation	yes
		4	Sandia Mts. East Peak	35°12'	106°20.5'	66	187	7,200	0.17	vegetation	yes
		5	Thompson Peak	35°41'	105°49'	45	107	10,100	1.39	vegetation	yes

(continued)

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[c] Readings taken from a different site; SV_r not calculated

TABLE 4. (Continued)

Location Number	Location Name	Target Number	Name	Lat (°N)	Long (°W)	Distance (km)	Azimuth Angle (°)	Elevation (feet)	Elevation Angle (°)	Target Cover	Calculate SV_r
13	White Sands National Monument		Entrance Station	29°20'	103°12'	0	---	4,000	---	---	
		1	95 degrees	29°12'	102°54'	30	95	9,000	2.91	vegetation	yes
		2	Flank of Sierra Blanca	29°28'	102°59'	69	31	9,200	1.32	vegetation	yes
		3	Capitol Peak	29°33'	103°07'	73	340	7,100	0.74	rock	no
		4	The Nose	29°30'	103°17'	38	297	6,400	1.10	rock	no
		5	Rattlesnake Ridge	29°39'	103°27'	67	209	6,600	0.68	rock	no
14	Carlsbad National Park		Tennis Courts	32°10'	104°27'	0	---	4,200	----	---	
		1	East Rim near Hunter Park	31°57.5'	104°48'	45.6	232	8,000	1.45	vegetation	yes
		2	Colored	31°56.5'	104°48'	48	228	6,300	0.76	1/5 vegetation	no
		3	Limestone Hill	31°53'	104°13'	45	144	3,600	-0.25	1/5 vegetation	no
15	Big Bend National Park		Maintenance Yard	29°20'	103°12'	0	---	3,840	---	---	
		1	Sierra Del Carmen Mts.	29°12'	102°54'	48	112	7,000	1.15	rock	yes
		2	Caballo Muerto	29°28'	102°59'	31	50	4,000	0.09	1/2 creosote	yes
		3	Dagger Mountain	29°33'	103°07'	27.5	22	3,800	-0.03	dark rock	yes
		4	Rosillo Mountains	29°30'	103°17'	20	344	3,800	-0.03	light brn rock	yes
		5	Nine Point Mesa	29°39'	103°27'	43	330	5,000	0.47	1/2 veg/1/2 dark rock	yes
16	Theodore Roosevelt National Memorial Park (south unit)		Scenic Viewpoint	46°53'	103°31'	0	---	2,490	---	---	
		1	Bullion Butte	46°42'	103°36'	27.4	195	3,250	0.48	grass	yes
		2	Sentinel Butte	46°53'	103°50'	25.7	254	3,400	0.62	grass	yes
17	Wind Caves National Park		Ridge	43°32'	103°29'	0	---	4,270	---	---	
		1	Rankin Ridge	43°37'	103°30'	11.3	359	4,600	0.51	ponderosa	yes
		2	Cicero Peak	43°41'	103°33'	17.7	354	5,800	1.51	1/3 ponderosa	no
		3	Alabaugh Ridge	43°36'	103°36'	16.1	321	4,550	0.30	9/10 ponderosa	yes
		4	Horseshoe Bend	43°19'	103°32'	22.5	195	3,900	-0.29	4/5 ponderosa	yes
		5	Buffalo Gap	43°31.5'	103°32'	16.1	90	3,360	-0.99	grassland and brown soil	no
18	Colorado National Monument		Campground-Picnic Area	39°6'	108°44'	0	---	5,720	---	---	
		1	Margarets Mt.	39°11.5'	109°38'	56	303	8,900	0.71	pine	yes
		2	Lookout Mountain	39°32'	108°50'	50	350	7,800	1.41	pine	yes
		3	Horse Ridge	39°22'	108°35'	38	27	6,400	0.37	scrub pine	yes
		4	Grand Mesa North	39°6.5'	108°14'	44	88	7,500	0.73	pinion pine	yes
		5	Grand Mesa South	39°53'	108°11'	51	117	7,500	0.62	piniuon pine	yes

(continued)

TABLE 4. (Continued)

Location Number	Location Name	Target Number	Name	Lat (°N)	Long (°W)	Distance (km)	Azimuth Angle (°)	Elevation (feet)	Elevation Angle (°)	Target Cover	Calculate SV_r
19	Rocky Mt. National Park		Headquarters	40°22'	105°33'	0	---	7,840	----	---	
		1	Pierson Mt.	40°17.5'	105°28'	10.9	135	9,500	2.66	evergreen	yes
		2	Estes Cone	40°17'	105°34'	8.0	187	11,006	6.88	evergreen	yes
		3	Longs Peak	40°15'	105°36.5'	13.7	202	14,050	7.86	rock	no
		4	Notchtop Mt.	40°19'	105°42'	12.9	247	12,129	5.79	rock	no
		5	Tombstone Ridge	40°22'	105°40'	8.4	270	10,800	6.13	evergreen	yes
21	Chiricahua National Monument		Massai Point	32°00'	109°20'	0	---	6,870	---	manzanita	
		1	Dos Cabezas	32°13'	109°37'	37	311	8,354	0.70	rock	no
		2	Cochise Stronghold	31°55'	109°58'	62	263	6,807	0.02	rock	yes
		3	Potter Peak	31°31'	109°57'	79	227	5,628	0.27	rock	yes
		4	Hatchet Mt.	31°37'	108°25'	94.5	116	7,356	0.09	rock	yes
		5	Steins Peak	32°20'	109°5'	43.4	35	6,520	-0.14	rock	no
22	Grand Tetons National Park		Windy Point	43°40'	110°43'	0	---	6,600	---	---	
		1	Snow King	46°28'	110°41'	24	135	8,000	0.50	pines	yes
		2	Indian Peak	43°20'	110°56'	42	208	9,600	0.70	pine/rock	yes
		3	Phillips Ridge	43°44'	110°52'	19	218	6,700	0.09	pines	yes
		4	Huckleberry Ridge	43°44'	110°35'	47	11	8,900	0.85	pines	yes
		5	Coulter Peak	43°58'	110°26'	45	23	8,100	0.97	pines	yes
23	Shenandoah National Park		Loft. Mt. Campground	38°15'	78°40'	0	---	3,360	---	---	
		1	Appalachian Mt. Ridge	38°35'	79°03'	42	324	2,100		forest, deciduous	yes
		2	Massanutten Pt.	38°23'	78°46'	18	330	2,200	-0.63	forest, deciduous	yes
		3	Rocky Mt.	38°19'	78°39'	9	9	2,300	-2.05	forest, deciduous	yes
		4	Grindstone	38°28'	78°32'	27.2	22	2,400	-0.81	forest, deciduous	yes
		5	High Top	38°20'	78°33'	14.0	45	2,840		forest, deciduous	yes
24	Capulin Mountain National Monument		Scenic View	36°47'	103°59'	0	---	7,700	---	---	
		1	Little Crater(Nameless)	36°35'	104°13'	31	224	7,800	0.00	vol. ash/cinder	yes
		2	Taos Ridge	36°36'	105°12'	125	287	9,200	0.00	pine	yes
		3	Willow Canyon Ridge	36°48'	104°36'	55	273	7,700	0.00	pj	yes
		4	Barilla Mesa	37°00'	104°15'	35	313	8,200	0.00	pj	yes
		5	Watervale Mesa	36°58'	104°58'	21	358	7,200	0.00	pj	yes
28	Death Valley National Monument		Water-Tank Furnace Creek	36°30.5'	116°51'	0	---	410	---	---	
		1	Sylvania Mts.	37°22'	117°44'	123	321	6,750	0.90	1/2 pj	yes
		2	Tucki Wash Peak	36°27.5'	117°4'	21	255	5,360	4.11	rock	yes
		3	Owl's Head Mountains	35°46'	116°48'	82	176	3,400	0.64	scrub	yes
		4	Golden Canyon	36°25'	116°50'	9.4	171.6	417	0.18	rock	yes
		5	Grapevine Mountains	36°46'	116°57'	30	343	4,700	2.67	soil	yes

(continued)

TABLE 4. (Continued)

Location Number	Location Name	Target Number	Name	Lat (°N)	Long (°W)	Distance (km)	Azimuth Angle (°)	Elevation (feet)	Elevation Angle (°)	Target Cover	Calculate SV_r
30	Yellowstone National Park		Administration Building	45°2'	110°43'	0	---	6,267	----	---	
		1	Monitor Peak, East Ridge	45°10'	110°39'	22.7	21	9,300	0.04	pine	yes
		2	Bear Creek Basin	45°6'	110°37'	17.5	27	8,000	0.03	pine above mining	yes
		3	Folson Peak	44°52'	110°30'	16.7	127	8,700	0.04	pine	yes
35, 36	Acadia National Park		Maintenance Area	44°22'	68°16'	0	---	500	---	---	
		1	Blue Hill	44°26'	68°15'	27	285	800	0.00	forest	yes
		2	Mt. Battie	44°14'	69°04'	67	256	1,000	0.00	forest	yes
39	Lake Tahoe Low		King's Beach	39°14'	120°02'	0	---	6,234	---	---	
		1	Deadman Point	39°07'	119°56'	15.5	157	6,400	0.00	forest	yes
		2	Gunbarrel	38°56'	119°55'	34.5	167	7,200	0.01	forest	yes
		3	8455	38°53'	119°56'	40	170	8,440	0.02	forest	yes
		4	Tahoe Mountain	38°55'	120°02'	36	182	6,800	0.01	forest	yes
		5	Ellis Peak	39°04'	120°12'	23.5	218	8,730	0.03	forest	yes
40	Lake Tahoe High		Stateline Fire Lookout	39°13'	120°01'	0	---	7,021	---	---	
		1	Deadman Point	39°07'	119°56'	14.5	161	6,400	-0.01	forest	yes
		2	Gunbarrel	38°56'	119°55'	34	169	7,200	0.00	forest	yes
		3	8455	38°53'	119°56'	39.5	172	8,440	0.01	forest	yes
		4	Tahoe Mountain	38°55'	120°02'	35.5	184	6,800	0.00	forest	yes
		5	Ellis Peak	39°04'	120°12'	24	222	8,730	0.02	forest	yes

TABLE 5. INHERENT SPECTRAL CONTRASTS AS A FUNCTION OF VEGETATION, LIGHTING AND WAVELENGTHS

	Wavelength (nanometers)			
	405	450	550	630
Vegetation				
Shade	-0.92	-0.92	-0.87	-0.83
1/2 Shade	-0.90	-0.88	-0.80	-0.74
Sun	-0.88	-0.84	-0.73	-0.65
Half Vegetation				
Shade	-0.91	-0.91	-0.86	-0.82
1/2 Shade	-0.88	-0.83	-0.70	-0.60
Sun	-0.86	-0.75	-0.53	-0.39

CAMERA NETWORK

Color photography at some sites was initiated during the fall of 1979 to document the effects of changing visual air quality on various vistas. Table 6 indicates the camera location, starting date, direction of view (azimuth angle) and teleradiometer targets for the camera network. A 135-mm lens provides a 14° view. The camera was typically centered on the teleradiometer target. Photographs were taken twice daily, at 9 a.m. and 3 p.m. local time.

TABLE 6. CAMERA NETWORK

Location Name	Azimuth Angle	Teleradiometer Target #	Starting Date
Grand Canyon National Park	293°	2	10/1/79
	163°	4	
	96°	5	
Bryce Canyon National Park	120°	1	11/1/79
	20°	4	
	311°	5	
Dinosaur National Monument	243°	2	9/1/79
	180°	4	
Mesa Verde National Park	220°	1	9/1/79
	200°	Shiprock	
	185°	3	
Olympic National Park	52°	2	4/30/80
	336°	4	
Navajo National Monument	325°	1	3/6/80
	260°	2	
Big Bend National Park	112°	1	9/4/79
	50°	2	
	22°	3	
Theodore Roosevelt National Memorial Park	195°	1	9/4/79
	254°	2	
Colorado National Monument	350°	2	1/12/81
	88°	4	
Chiricahua National Monument	263°	2	6/5/81
	116°	4	
Shenandoah National Park	330°	2	5/5/80
	9°	3	
	22°	4	
	45°	5	

DATA PROCESSING

The flow of data from observation to final graphics is shown in Figure 10. Each day the observer recorded the date, location code, meteorological and snow codes, ratios and target radiance values on a data sheet. These data sheets were mailed to the John Muir Institute-Visibility Research Center (VRC) each month where they were visually checked for obvious errors. Operators were notified when errors appear and changes were suggested. The data were keypunched on cards, verified, and computer-stored. The ratios were checked manually for several kinds of errors or anomalies.

Editing was designed to produce a data set of uniform quality. Data that failed the editing tests were maintained, though specifically labeled, in the time plots of apparent contrast. Raw and edited data could then be compared in order to help observers and analysts reduce the occurrence of these errors in the future. Three tests were applied to each measurement: "in sky," "Rayleigh contrast," and "spectral consistency" tests. The "in sky" test assumes that contrasts between -0.01 and +0.01 occur only when the teleradiometer was mistakenly aimed so that both sky and target detector readings were taken in the sky. The "Rayleigh contrast" test rejects apparent contrasts that are less than (more negative than) the lowest possible calculated contrast for a dark target viewed through an unpolluted or a Rayleigh atmosphere. The "spectral consistency" test identifies spectral ratios that significantly departed from the monthly mean of the ratios at that wavelength. It is based on an assumption that for dark targets, departures for all four wavelengths would tend to vary in a similar way. If the departure of a ratio differed too greatly from concurrent ratios at other wavelengths, it was rejected. Details of this test are discussed in Appendix A. None of these questionable apparent contrasts are used in statistical computations.

Although the teleradiometer was used to measure the apparent spectral ratio at four wavelengths, only the 550-nm ratios were used to compute standard visual range because the human eye has its peak response at the 550-nm central wavelength of the green filter.

Summary statistics were computed monthly, seasonally and for the entire period of record. The geometric mean is the appropriate averaging statistic because standard visual range is log-normally distributed. The 90-percent confidence limits are one measure of the variability of the individual standard visual range. They are related to the standard deviation and the number of readings. If the confidence intervals around two means do not overlap, it can be concluded that at a 90-percent confidence level the two means are significantly different.

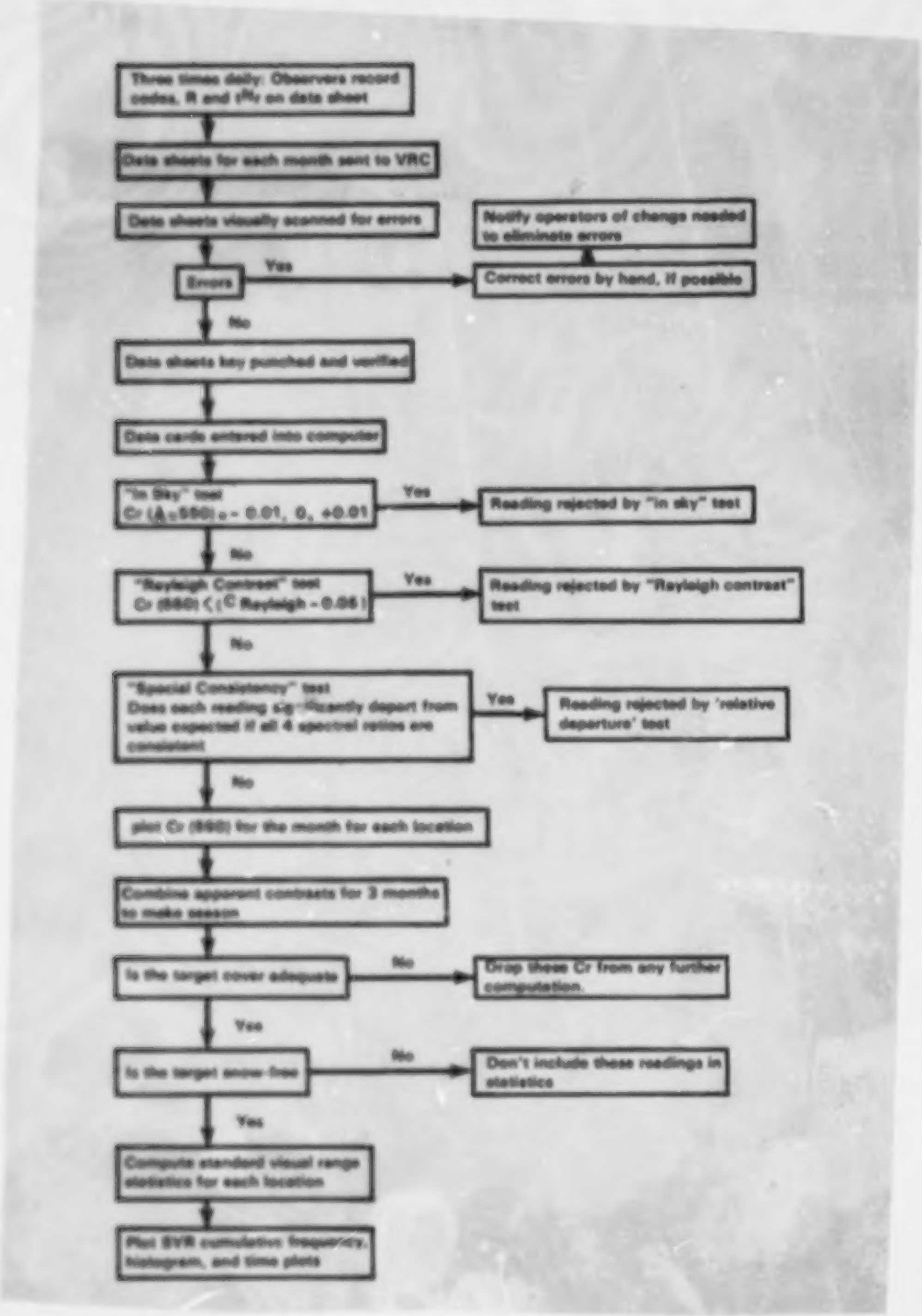
Three times daily: Observers record codes, R and $t^{R}r$ on data sheet
Data sheets for each month sent to VRC
Data sheets visually scanned for errors
Errors
Yes
Correct errors by hand, if possible
Notify operators of change needed to eliminate errors
No
Data sheets key punched and verified
Data cards entered into computer
"In Sky" test
Cr (λ=550)$_0$ - 0.01, 0, +0.01
Yes
Reading rejected by "in sky" test
No
"Rayleigh Contrast" test
Cr (550) < ($C_{Rayleigh}$ - 0.05)
Yes
Reading rejected by "Rayleigh contrast" test
No
"Special Consistency" test
Does each reading significantly depart from value expected if all 4 spectral ratios are consistent
Yes
Reading rejected by 'relative departure' test
No
plot Cr (550) for the month for each location
Combine apparent contrasts for 3 months to make season
Is the target cover adequate
No
Drop these Cr from any further computation.
Yes
Is the target snow-free
No
Don't include these readings in statistics
Yes
Compute standard visual range statistics for each location
Plot SVR cumulative frequency, histogram, and time plots

Figure 10. Flow of data from manual teleradiometers to final graphics.

SUMMARY OF RESULTS

Teleradiometer data collected during fourteen seasons of monitoring are summarized in Table 7 and Appendices B and C. Table 7 lists seasonal statistics of standard visual range calculations: geometric mean, 90% confidence intervals, and the number of valid measurements collected at each site. Since snow covered targets are not used in standard visual range calculations, the winter seasons at a number of the locations have very few valid measurements. The values calculated for these winter seasons should be used with care.

The Big Bend, Chiricahua, and Death Valley sites all have targets which are sparsely vegetated. Standard visual ranges calculated at these sites are intended for interseason comparison at each location and are not recommended for comparison with other locations.

Appendix B contains time plots for each location of monthly geometric mean standard visual range. The 90% confidence levels are indicated by cross hatching. In order to generate meaningful statistics, only those months that have 11 or more valid measurements of standard visual range are plotted.

The data in Table 7 and Appendix B show strong seasonal variations in standard visual range at all the monitoring locations. Maximum values occur during the fall and winter months with minimums during the spring and summer. The causes of these seasonal fluctuations are not addressed in this report. Further studies in this area are in progress.

Appendix C contains total cumulative frequency distributions of standard visual range for each location. These plots represent all the valid standard visual range measurements made at a location during the period that monitoring was in effect. Frequency of occurrence of standard visual range at each monitoring site can be taken from these distributions. The 10%, 50%, and 90% levels are indicated on each plot. Figure 11 is a map showing the 50% levels for sites with at least one year of data. Isopleths on the map indicate that the area of greatest measured median visibility is primarily the Colorado Plateau.

Though the camera monitoring network was responsible for collecting over 20,000 color slides, the qualitative nature of this type of information does not lend itself to data summary. This photographic record has been made available to researchers investigating western regional visibility, and has been proven to be a valuable source of information.

TABLE 7. SEASONAL MEAN STANDARD VISUAL RANGE (KM)[a]

Season[b] Year	Canyonlands Island in the Sky 1	Grand Canyon 2	Canyonlands Hans Flat 3	Bryce Canyon 4	Capitol Reef 5	Dinosaur 6	Mesa Verde 7	Olympic 8	Wupatki 9	Navajo 10
Summer 1978	NO DATA	172 (168- 177) 642	NI[c]	178 (173- 184) 228	190 (185- 194) 570	192 (186- 198) 223	169 (164- 174) 207	NI	166 (154- 179) 22	192 (177- 209) 68
Fall 1978	200 (194- 206) 366	208 (203- 213) 809	NI	208 (202- 215) 327	215 (209- 222) 509	NO DATA	185 (180- 191) 336	NI	122 (114- 131) 254	191 (185- 198) 511
Winter 1978/1979	251 (184- 341) 7	248 (213- 288) 24	NI	259 (240- 279) 30	NO DATA	205 (147- 286) 8	NO DATA	NI	188 (161- 218) 28	NO DATA
Spring 1979	169 (161- 178) 90	159 (151- 166) 236	136 (130- 142) 81	144 (138- 150) 114	171 (163- 179) 209	168 (153- 185) 14	153 (142- 165) 48	NI	201 (169- 233) 16	160 (152- 169) 154
Summer 1979	189 (185- 193) 413	178 (175- 181) 1,023	166 (164- 169) 672	170 (166- 173) 920	175 (171- 179) 682	177 (174- 181) 593	182 (178- 186) 482	NI	159 (153- 166) 259	164 (160- 167) 632
Fall 1979	190 (185- 195) 456	194 (190- 199) 990	176 (172- 180) 506	195 (190- 199) 757	189 (184- 195) 580	192 (187- 196) 414	184 (179- 189) 323	NI	162 (155- 168) 339	175 (171- 180) 474
Winter 1979/1980	194 (177- 213) 51	276 (265- 287) 296	206 (193- 220) 75	289 (280- 299) 218	216 (203- 230) 5	NO DATA	189 (148- 242) 2	NI	215 (191- 243) 57	264 (181- 384) 7
Spring 1980	182 (171- 193) 99	130 (122- 138) 269	151 (145- 157) 126	129 (117- 142) 26	164 (157- 171) 245	102 (96- 109) 3	139 (123- 156) 113	140 (124- 158) 65	141 (133- 148) 80	145 (138- 153) 165
Summer 1980	190 (187- 193 482	159 (156- 162) 1,122	158 (156- 161) 583	138 (135- 142) 662	164 (160- 168) 672	151 (145- 157) 356	176 (172- 180) 538	138 (126- 151) 75	158 (153- 163 315	168 (164- 171) 678
Fall 1980	206 (200- 211) 353	219 (213- 224) 910	180 (176- 184) 426	223 (219- 228) 798	206 (199- 214) 357	203 (199- 208) 457	201 (197- 205) 466	152 (139- 167) 128	180 (172- 189) 229	230 (224- 237) 564
Winter 1980/1981	241 (209- 278) 10	264 (258- 271) 626	174 (165- 182) 252	280 (274- 286) 591	159 (109- 231) 15	209 (191- 229) 65	235 (225- 246) 141	178 (155- 205) 66	166 (149- 187) 52	256 (245- 267) 204
Spring 1981	192 (185- 200) 168	180 (176- 185) 706	NI	192 (187- 197) 453	204 (193- 216) 179	166 (160- 173) 255	190 (185- 195) 276	151 (129- 176) 36	170 (162- 178) 201	192 (185- 183) 332
Summer 1981	165 (162- 169) 498	138 (135- 140) 944	NI	159 (157- 162) 793	160 (156- 163) 707	145 (142- 148) 357	153 (150- 157) 456	NI	141 (137- 145) 459	152 (149- 155) 620
Fall 1981	205 (200- 211) 369	203 (198- 208) 1,091	NI	206 (201- 211) 600	207 (201- 214) 513	NI	172 (166- 178) 443	NI	176 (169- 183) 402	218 (211- 225) 465

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[a] Order of presentation for each entry is geometric mean, (90% confidence interval), and number of values. Calculated for snow-free targets regardless of cloud condition.

[b] Seasons are: Summer - June, July, August; Fall - September, October, November; Winter - December, January, February; Spring - March, April, May.

[c] NI = No instrument.

TABLE 7. (Continued)

Season Year	Chaco Canyon[d] 11		Bandelier 12	White Sands 13	Carlsbad 14	Big Bend[e] 15	Roosevelt 16	Cave 17	Colorado National Monument 18	Rocky Mountain 19
Summer 1978	187 (181- 193) 115	NO DATA	172 (166- 177) 335	118 (111- 124) 155	157 (145- 171) 42	148 (140- 158) 234	NI	NI	NI	NI
Fall 1978	203 (198- 208) 270	225 (201- 251) 11	155 (151- 158) 681	125 (119- 131) 269	179 (163- 197) 55	130 (125- 136) 455	NI	NI	NI	NI
Winter 1978/1979	NO DATA	264 (228- 302) 3	226 (207- 247) 33	190 (174- 207) 89	245 (218- 275) 29	212 (192- 234) 75	NI	NI	NI	NI
Spring 1979	188 (175- 201) 22	184 (166- 205) 12	284 (284- 284) 1	143 (137- 148) 297	151 (132- 173) 19	163 (157- 168) 579	120 (111- 130) 100	123 (105- 142) 34	NI	NI
Summer 1979	198 (195- 202) 250	184 (177- 190) 87	148 (145- 150) 801	114 (111- 118) 418	139 (133- 145) 191	154 (150- 158) 1,008	113 (109- 118) 366	145 (138- 154) 301	NI	NI
Fall 1979	198 (194- 202) 331	190 (184 197) 103	149 (146- 153) 689	115 (111- 119) 424	142 (136- 149) 174	146 (142- 150) 905	154 (147- 161) 282	179 (162- 198) 102	NI	NI
Winter 1979/1980	298 (271- 327) 2	348 (348- 348) 1	186 (178- 194) 191	159 (153- 165) 329	206 (194- 219) 146	174 (168- 179) 862	230 (206- 258) 54	NO DATA	NI	NI
Spring 1980	176 (169- 183) 67	211 (192- 231) 23	174 (169- 180) 210	132 (128- 136) 423	197 (169- 231) 13	168 (163- 173) 838	100 (95- 105) 246	111 (102- 122) 100	NI	NI
Summer 1980	180 (177- 183) 384	237 (226- 249) 119	164 (161- 167) 940	119 (115- 113) 411	NI	138 (135- 141) 1,054	131 (127- 135) 389	163 (157- 170) 485	177 (174- 180) 877	157 (150- 165) 481
Fall 1980	213 (207- 219) 190	195 (185- 205) 65	176 (172- 180) 613	139 (134- 145) 321	NI	146 (141- 152) 577	195 (185- 205) 291	194 (180- 210) 163	204 (199- 208) 681	239 (226- 253) 332
Winter 1980/1981	257 (240- 275) 58	210 (197- 224) 64	221 (213- 228) 335	177 (171- 183) 356	NI	208 (202- 215) 965	211 (197- 227) 194	209 (167- 262) 48	235 (228- 242) 427	278 (258- 300) 211
Spring 1981	177 (172- 183) 102	188 (180- 197) 43	187 (182- 192) 519	141 (136- 145) 376	NI	183 (178- 189) 1,043	130 (122- 138) 213	185 (171- 200) 146	190 (182- 199) 243	221 (197- 247) 120
Summer 1981	163 (160- 167) 183	167 (159- 176) 48	147 (144- 150) 828	112 (109- 116) 322	NI	139 (135- 143) 1,156	115 (110- 121) 368	159 (152- 165) 523	171 (167- 175) 659	193 (181- 206) 269
Fall 1981	208 (195- 222) 68	208 (188- 230) 23	176 (172- 181) 659	133 (127- 139) 284	NI	143 (139- 148) 1,040	135 (126- 145) 225	128 (117- 140) 123	183 (176- 189) 307	199 (185- 214) 310

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[d] Chaco Canyon values for target 6 are in the second column, all other targets in the first columns.
[e] This site has no satisfactory targets. Visual range values should not be compared to other locations.

TABLE 7. (Continued)

Season Year	Chiricahua[e] 21	Grand Tetons 22	Shenandoah 23	Capulin 24	Death Valley[e] 28	Yellowstone 30
Summer 1978	NI	NI	NI	NI	NI	NI
Fall 1978	NI	NI	NI	NI	NI	NI
Winter 1978/1979	NI	NI	NI	NI	NI	NI
Spring 1979	NI	NI	NI	NI	NI	NI
Summer 1979	NI	NI	NI	NI	NI	NI
Fall 1979	NI	NI	NI	NI	NI	NI
Winter 1979/1980	NI	NI	NI	NI	250 (225-277) 36	NI
Spring 1980	NI	NI	50 (47-54) 179	137 (131-143) 338	171 (162-181) 294	NI
Summer 1980	NI	152 (147-157) 470	39 (37-41) 489	139 (136-143) 973	145 (138-152) 420	NI
Fall 1980	NI	172 (166-178) 539	63 (60-67) 377	207 (201-213) 819	235 (226-244) 535	NI
Winter 1980/1981	NI	NO DATA	NO DATA	273 (267-280) 870	294 (285-303) 501	NI
Spring 1981	NI	NO DATA	35 (31-40) 24	180 (175-187) 606	204 (195-213) 495	NI
Summer 1981	145 (141-148) 388	147 (143-150) 1,018	41 (39-44) 399	160 (156-164) 849	142 (137-148) 616	177 (171-184) 529
Fall 1981	244 (236-253) 426	151 (146-156) 755	72 (67-77) 185	201 (195-207) 873	220 (211-230) 487	161 (151-171) 338

[e] This site has no satisfactory targets. Visual range values should not be compared to other locations.

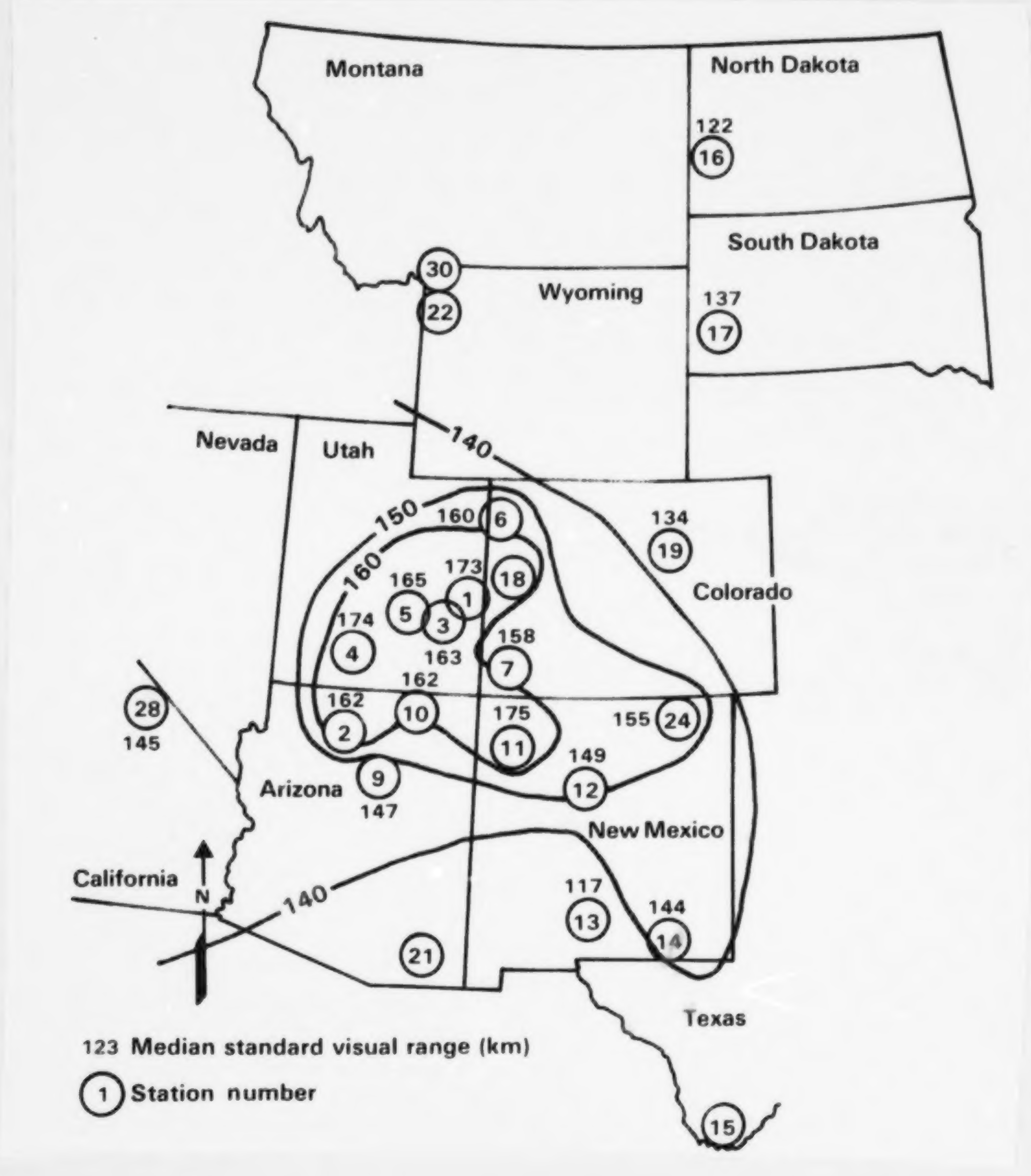
Montana
North Dakota
122
16
South Dakota
30
22
Wyoming
137
17
Nevada
Utah
140
150
160
6
134
19
Colorado
165
173
1
18
5
3
174
4
158
163
7
162
28
162
10
175
155
24
145
2
11
149
Arizona
9
12
147
New Mexico
California
N
140
117
13
144
14
21
Texas
15
123 Median standard visual range (km)
1 Station number

Figure 11. Median standard visual range (km), summer 1978 through fall 1981.

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Middleton, W. E. K. 1952. Vision through the atmosphere. University of Toronto Press, Toronto, Canada.

APPENDIX A

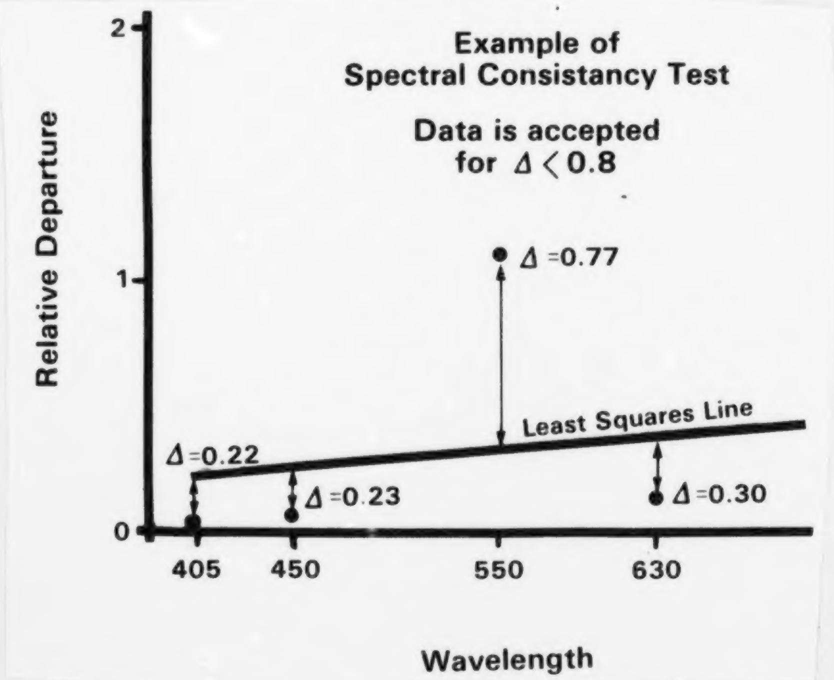
THE SPECTRAL CONSISTENCY EDITING TEST

The arithmetic mean and standard deviation of the ratios of target to sky apparent spectral radiance ($\overline{R}$ and SD) are computed for a 1-month period for each target, time of day and wavelength. The relative departure (DEP) of each ratio (R) is computed using the relation

$$DEP = ABS\ (\frac{R - \overline{R}}{SD})$$

where ABS is the absolute value of expression in parentheses.

The test can be graphically illustrated as shown below. The dots mark the relative departures of specific spectral ratios. These are used to compute the least squares fit straight line. If the difference between a point and the line is less than 0.8 then the ratio is accepted. The 0.8 was selected from tests on early Grand Canyon data as appropriate to eliminating obviously incorrect ratios.

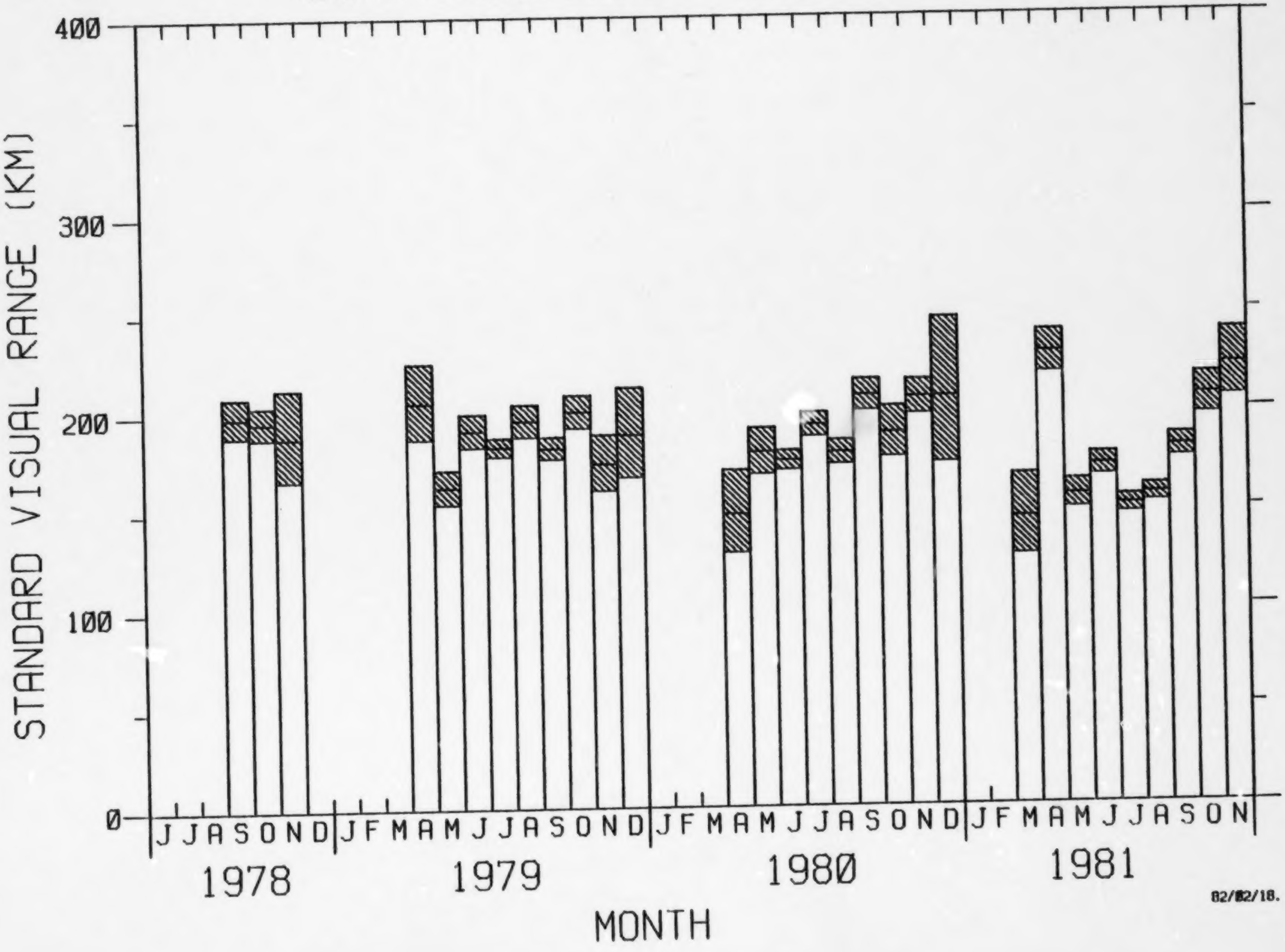


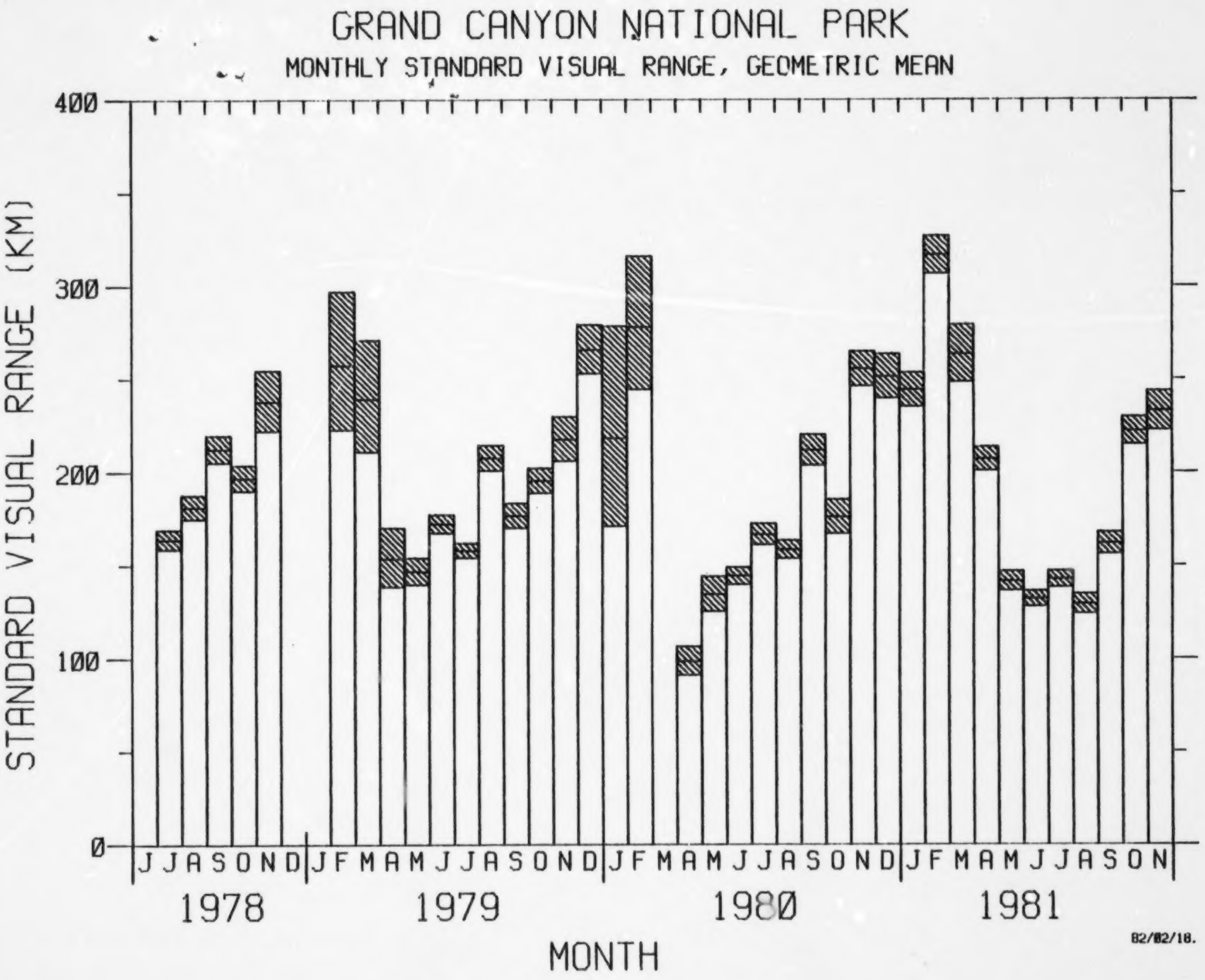
APPENDIX B

TIME PLOTS OF MONTHLY STANDARD VISUAL RANGE GEOMETRIC MEAN, 90% CONFIDENCE LEVELS

CANYONLANDS NATIONAL PARK, ISLAND IN THE SKY

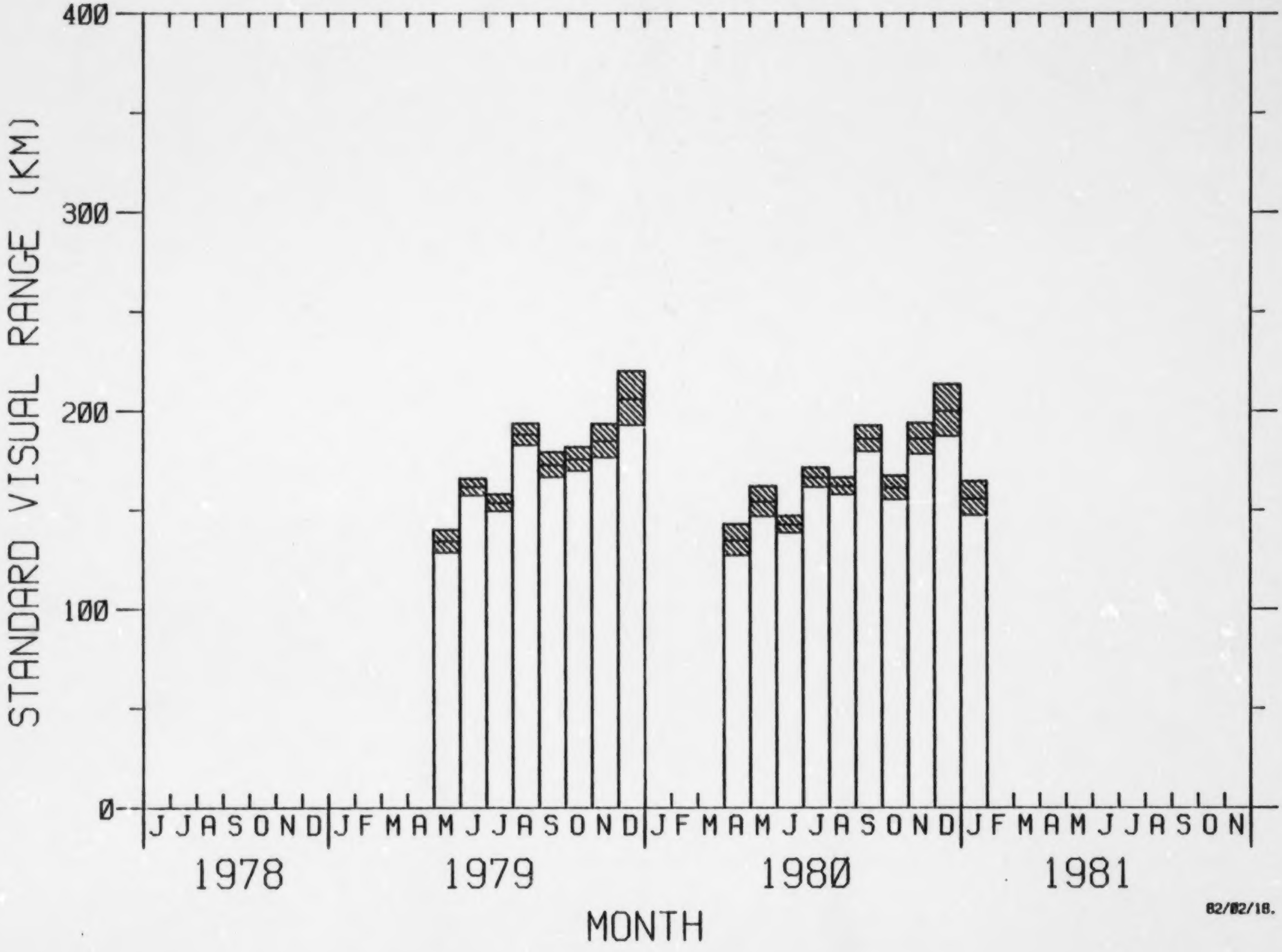
MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN




GRAND CANYON NATIONAL PARK
MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN
STANDARD VISUAL RANGE (KM)
400
300
200
100
0
J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N
1978
1979
1980
1981
MONTH
82/02/18.

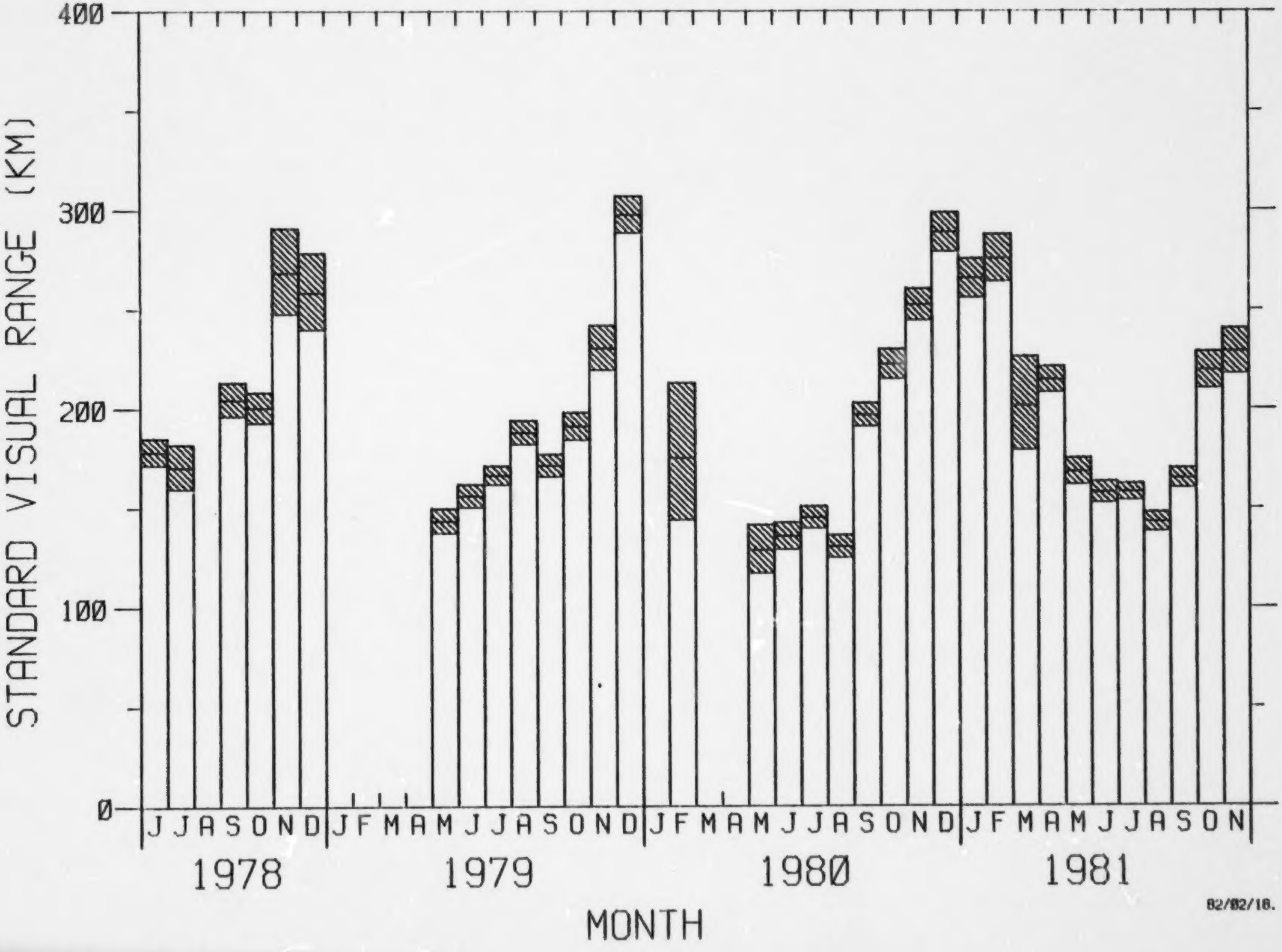
CANYONLANDS NATIONAL PARK, HANS FLAT

MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN



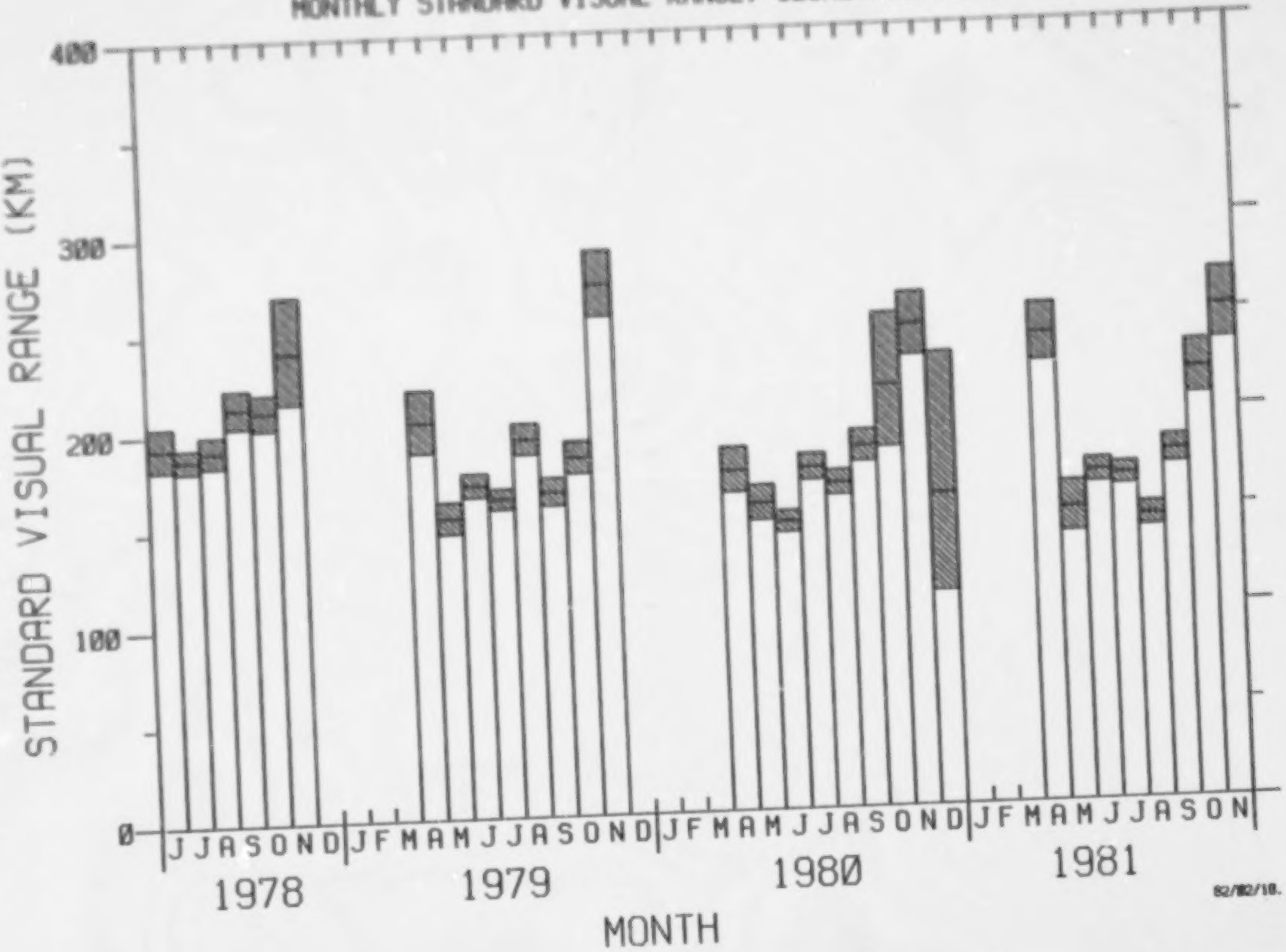
BRYCE CANYON NATIONAL PARK

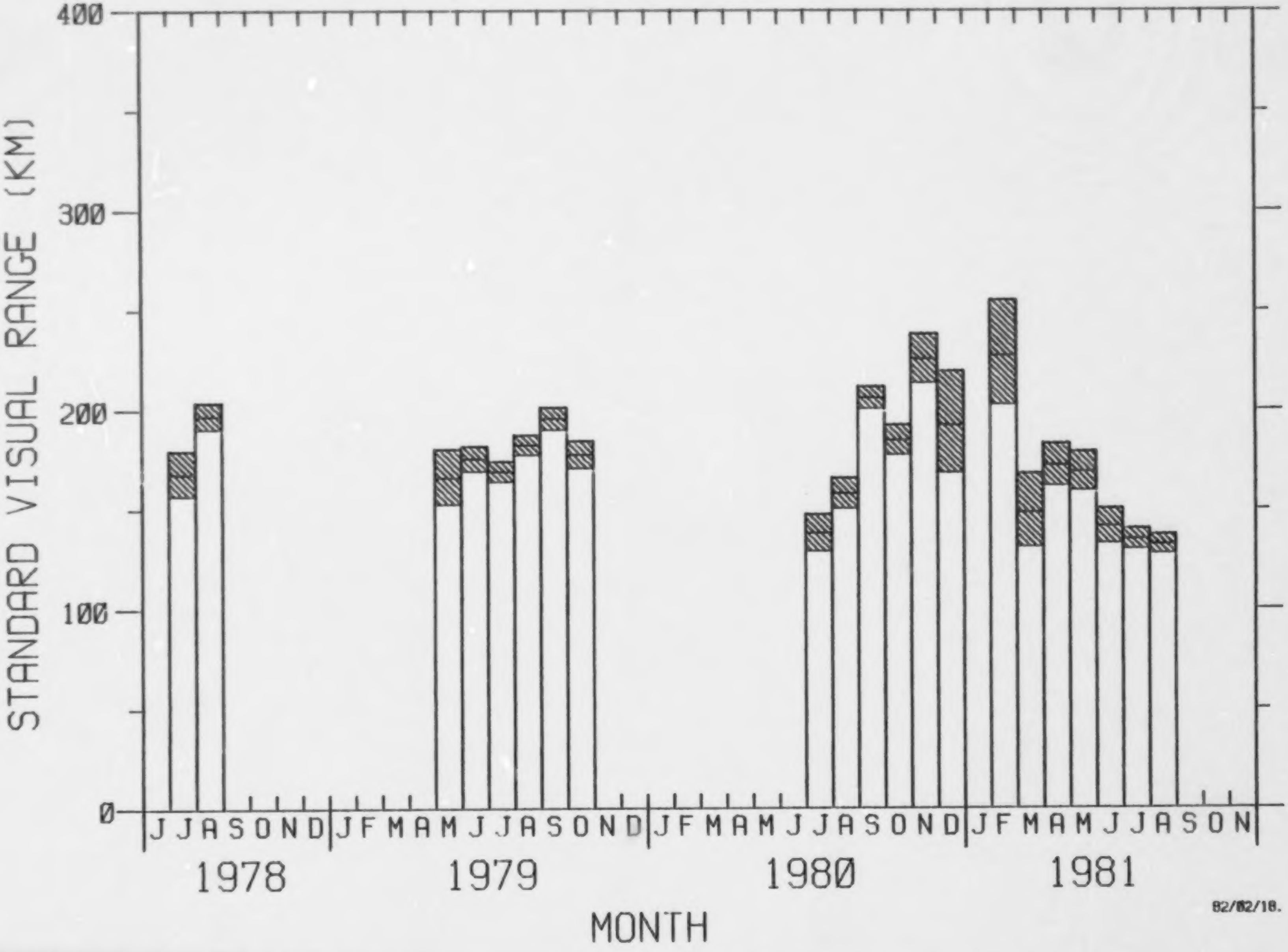
MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN



CAPITOL REEF NATIONAL PARK

MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN



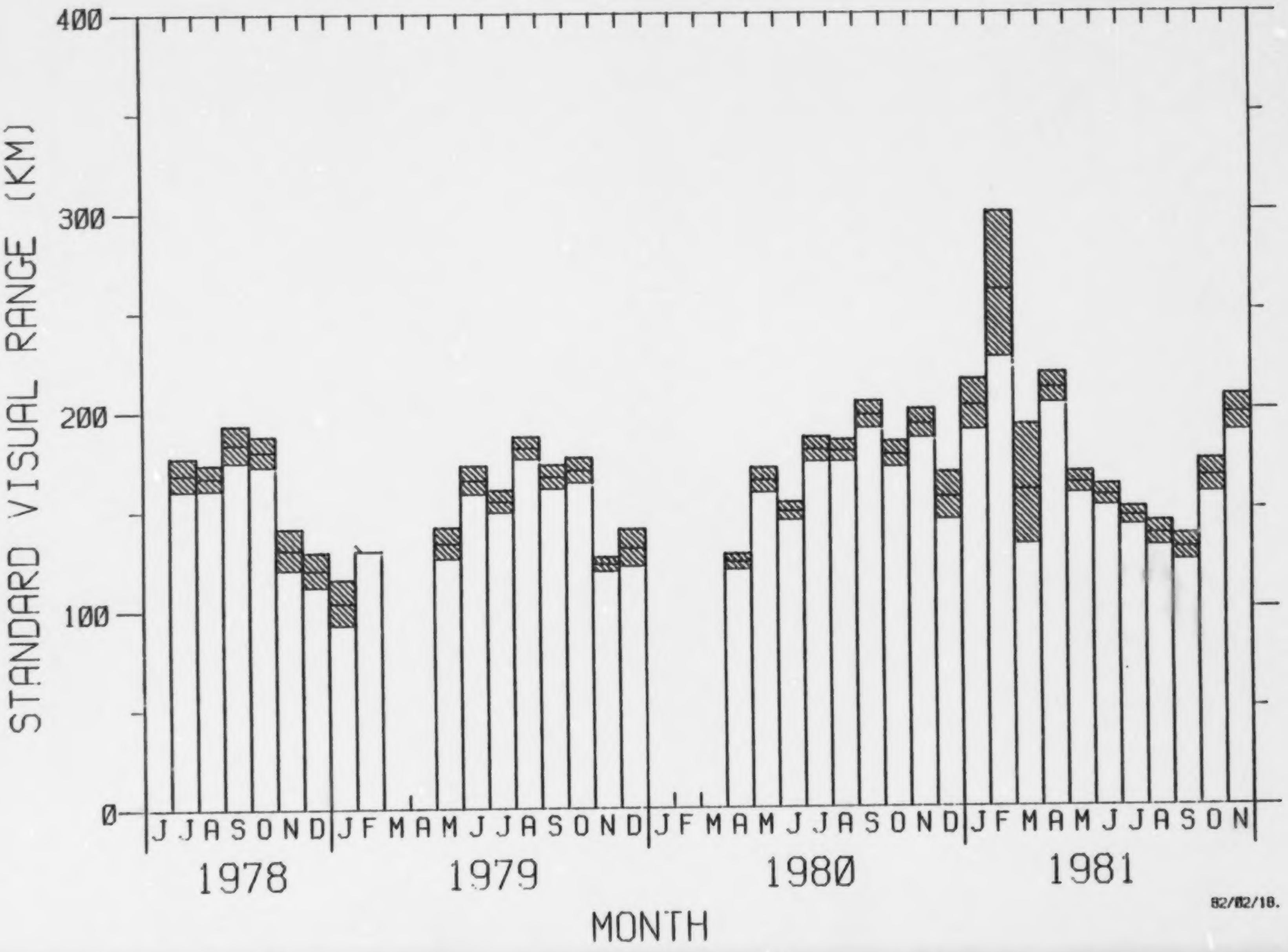


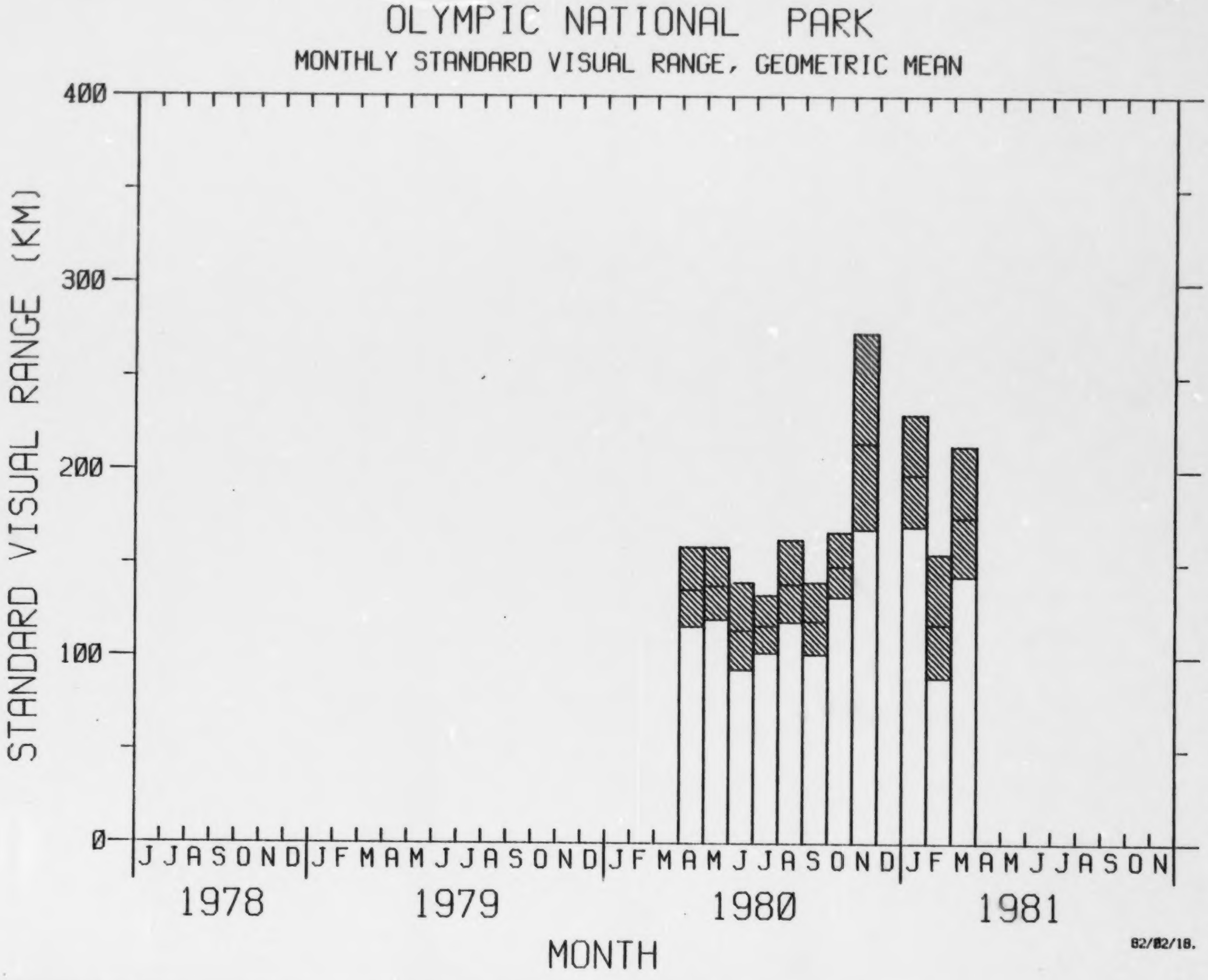
DINOSAUR NATIONAL MONUMENT

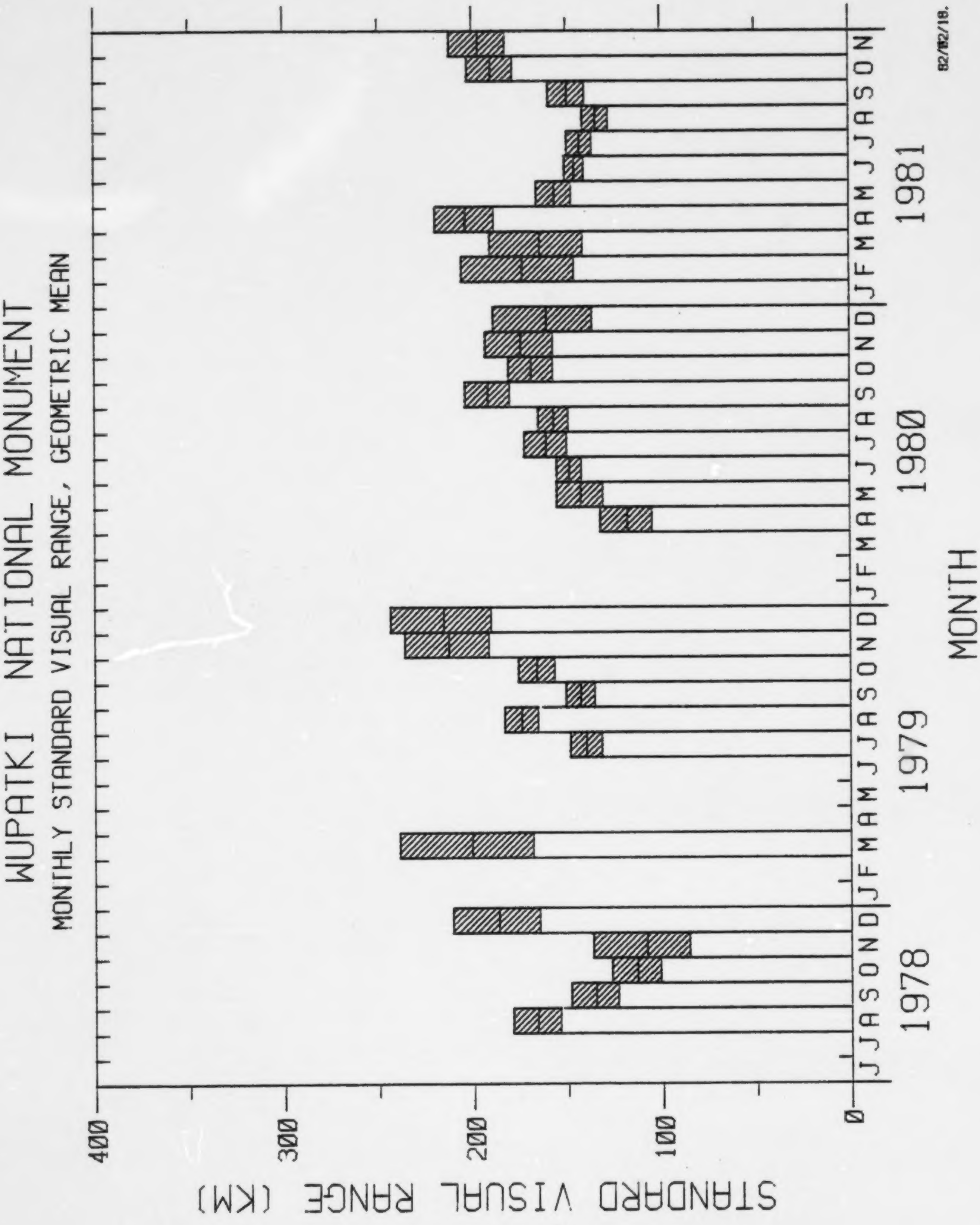
MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN

MESA VERDE NATIONAL PARK

MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN

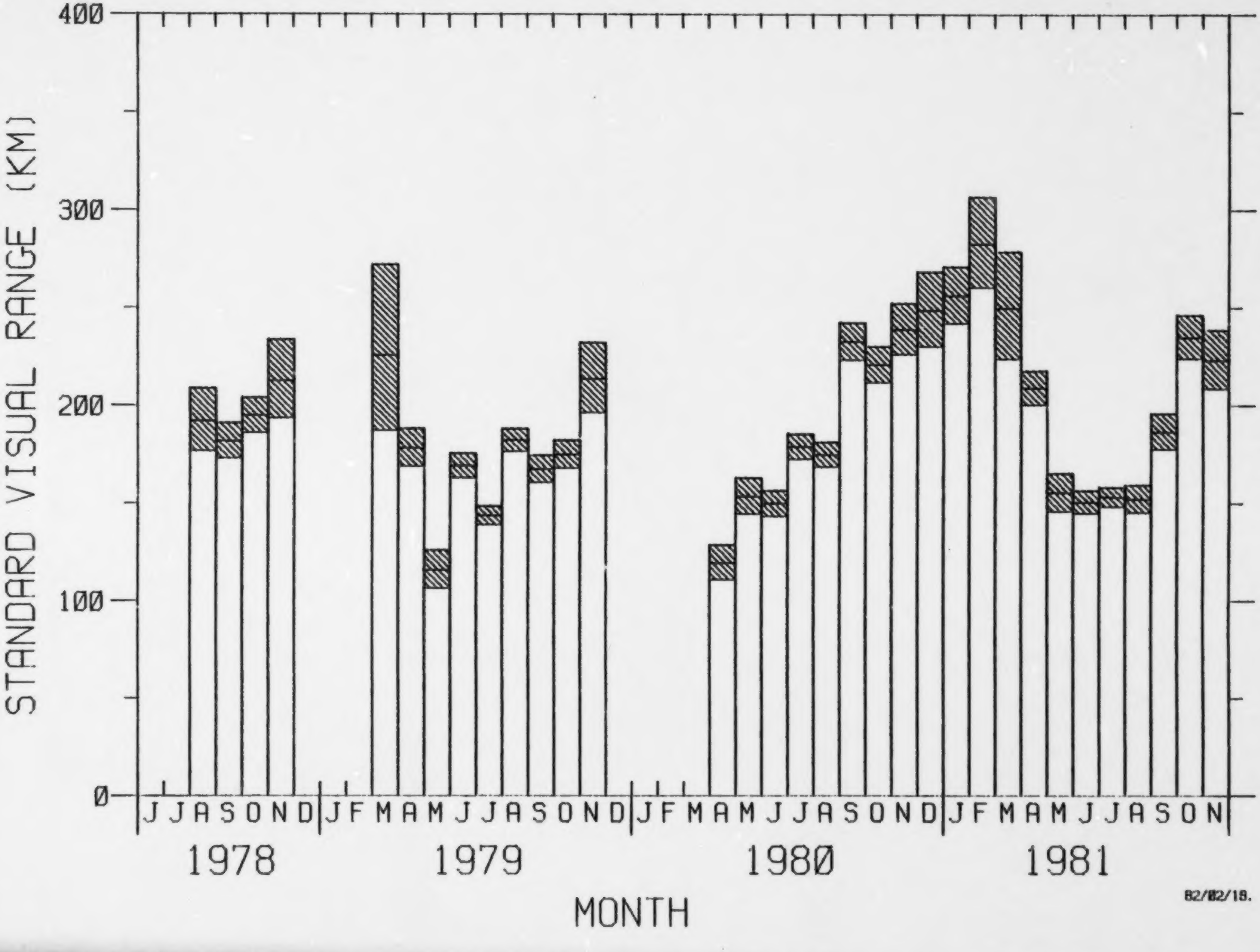



OLYMPIC NATIONAL PARK
MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN
STANDARD VISUAL RANGE (KM)
400
300
200
100
0
J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N
1978
1979
1980
1981
MONTH
82/02/18.



WUPATKI NATIONAL MONUMENT

MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN

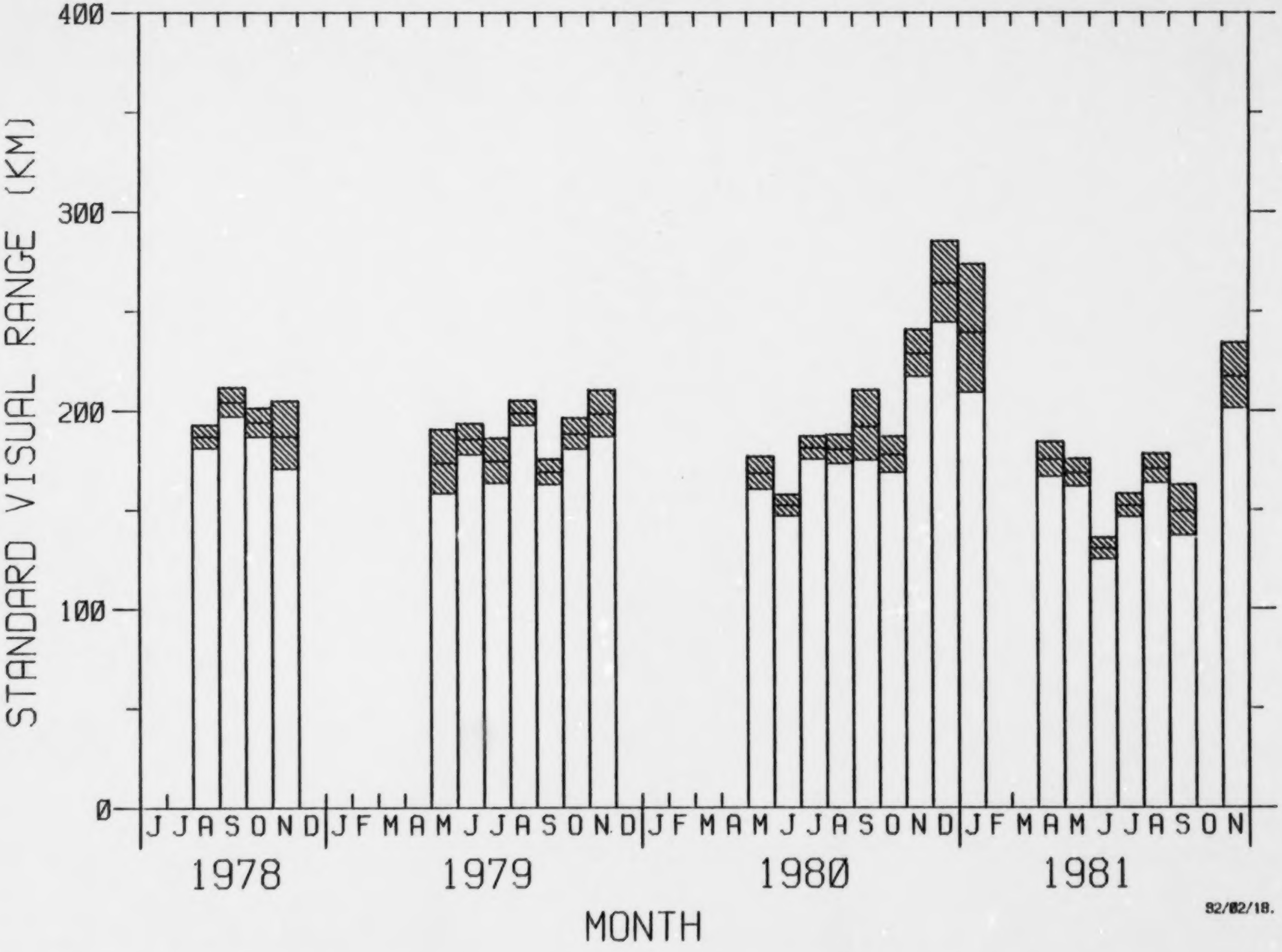


NAVAJO NATIONAL MONUMENT

MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN

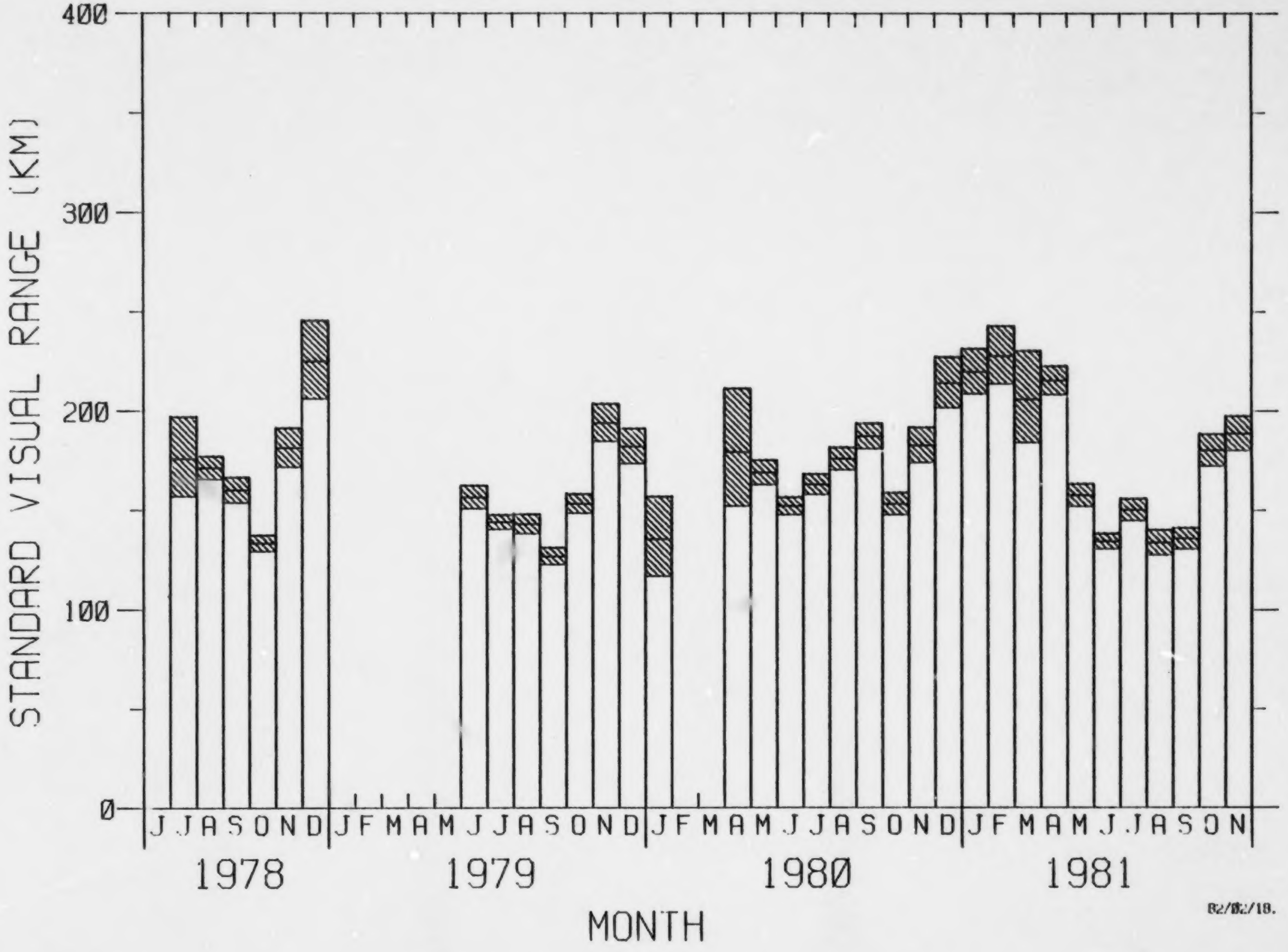
CHACO CANYON NATIONAL CULTURAL PARK

MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN



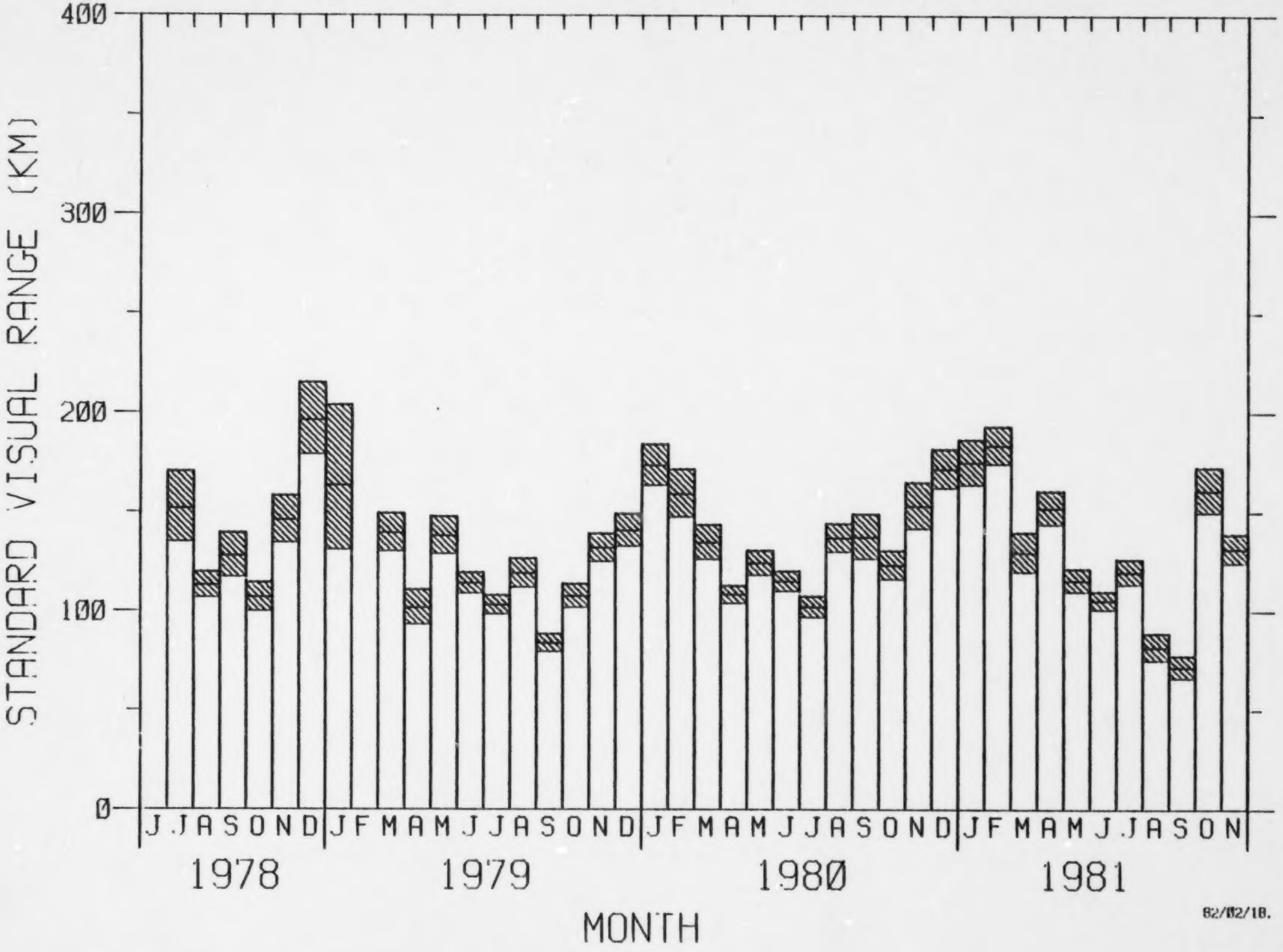
BANDELIER NATIONAL MONUMENT

MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN



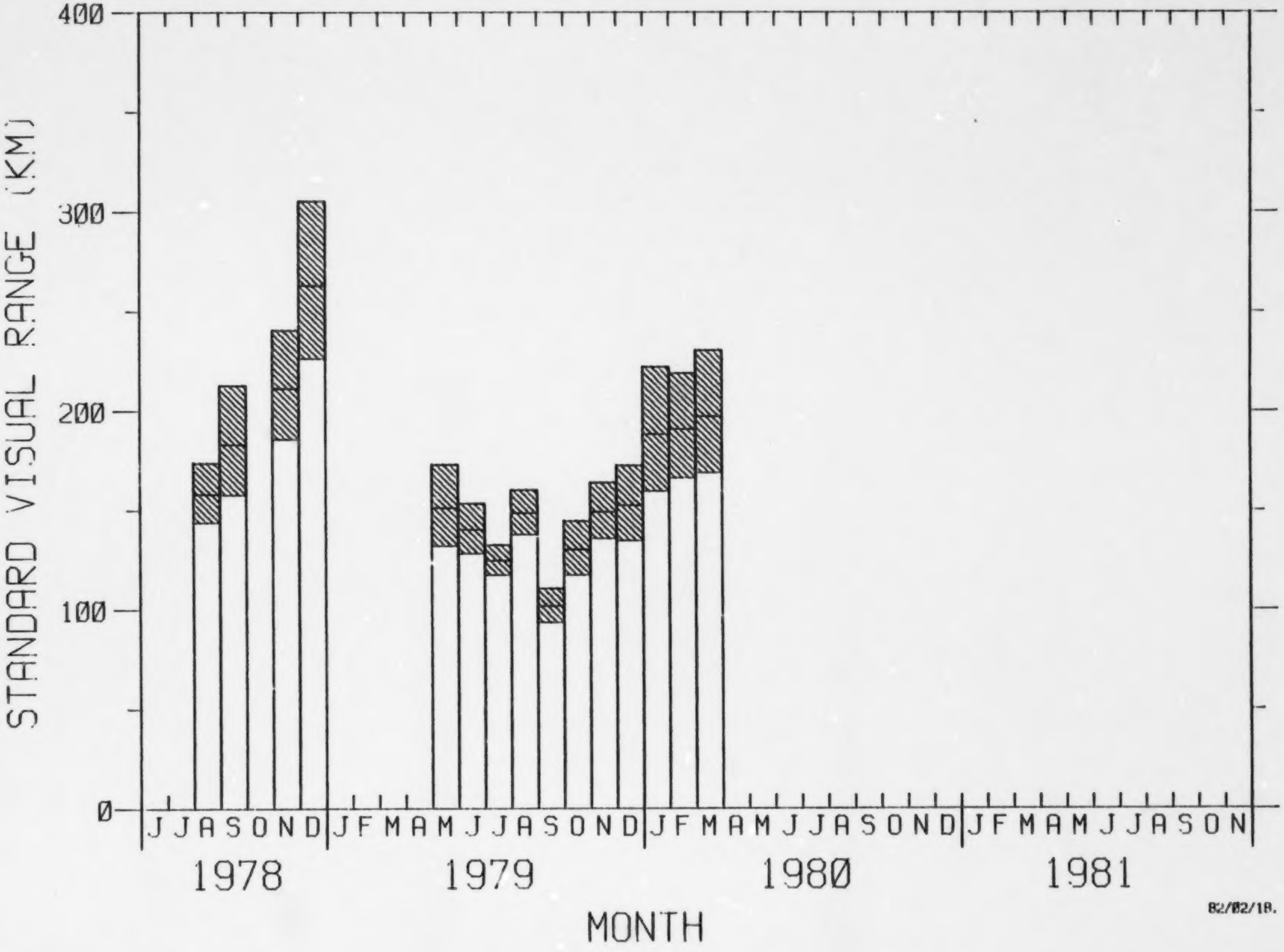
WHITE SANDS NATIONAL MONUMENT

MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN



CARLSBAD CAVERNS NATIONAL PARK

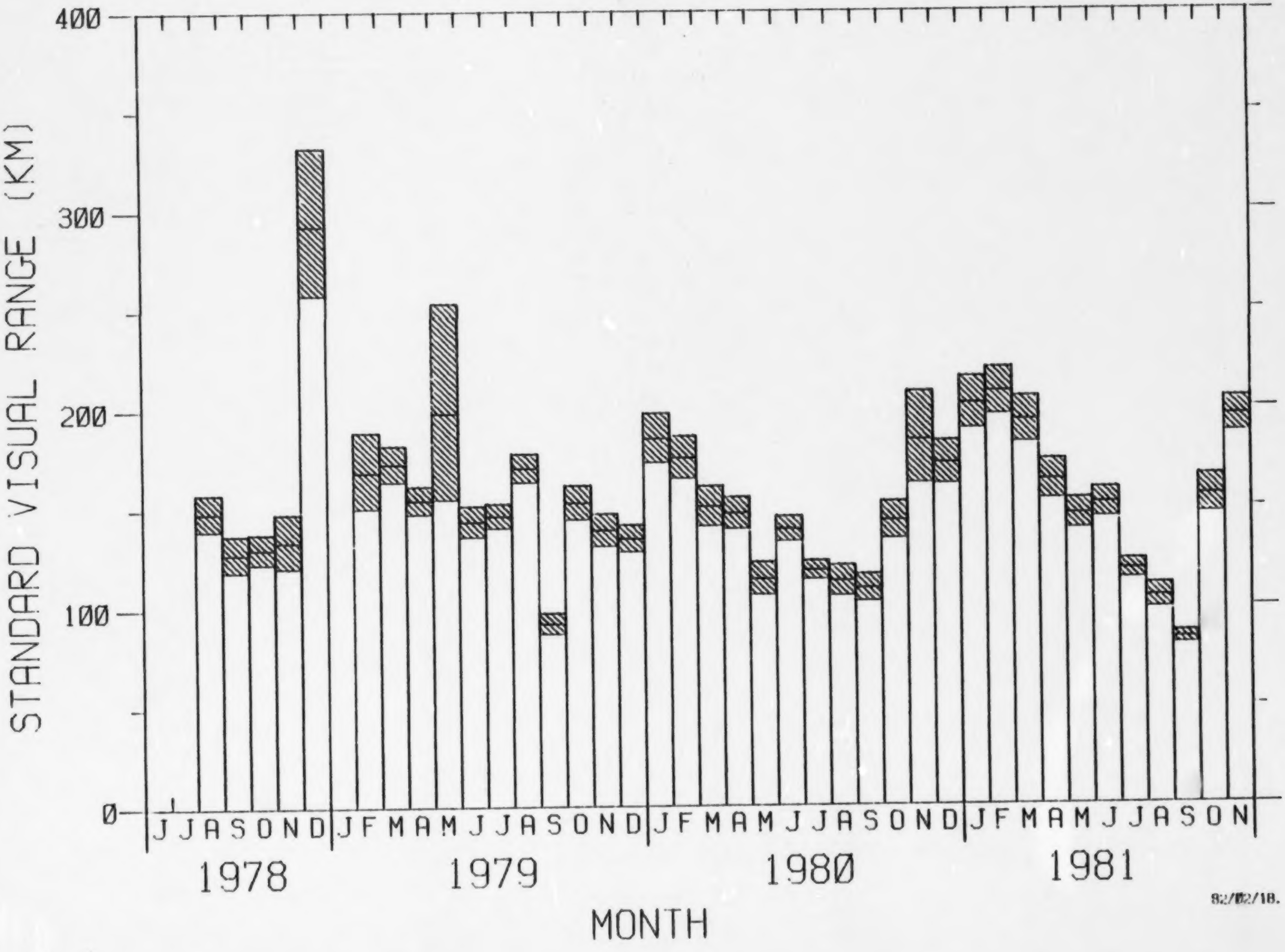
MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN



82/02/18.

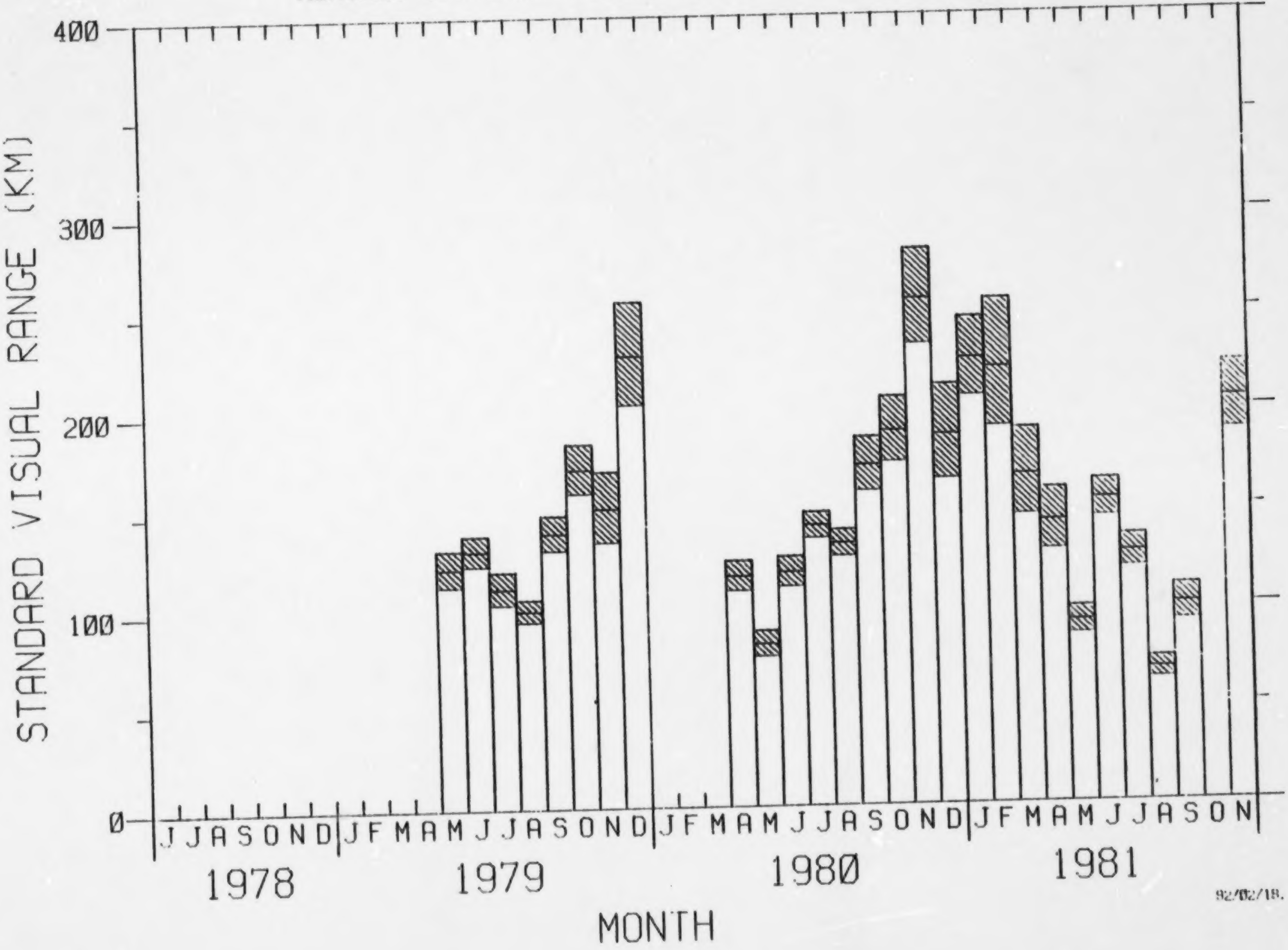
BIG BEND NATIONAL PARK

MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN



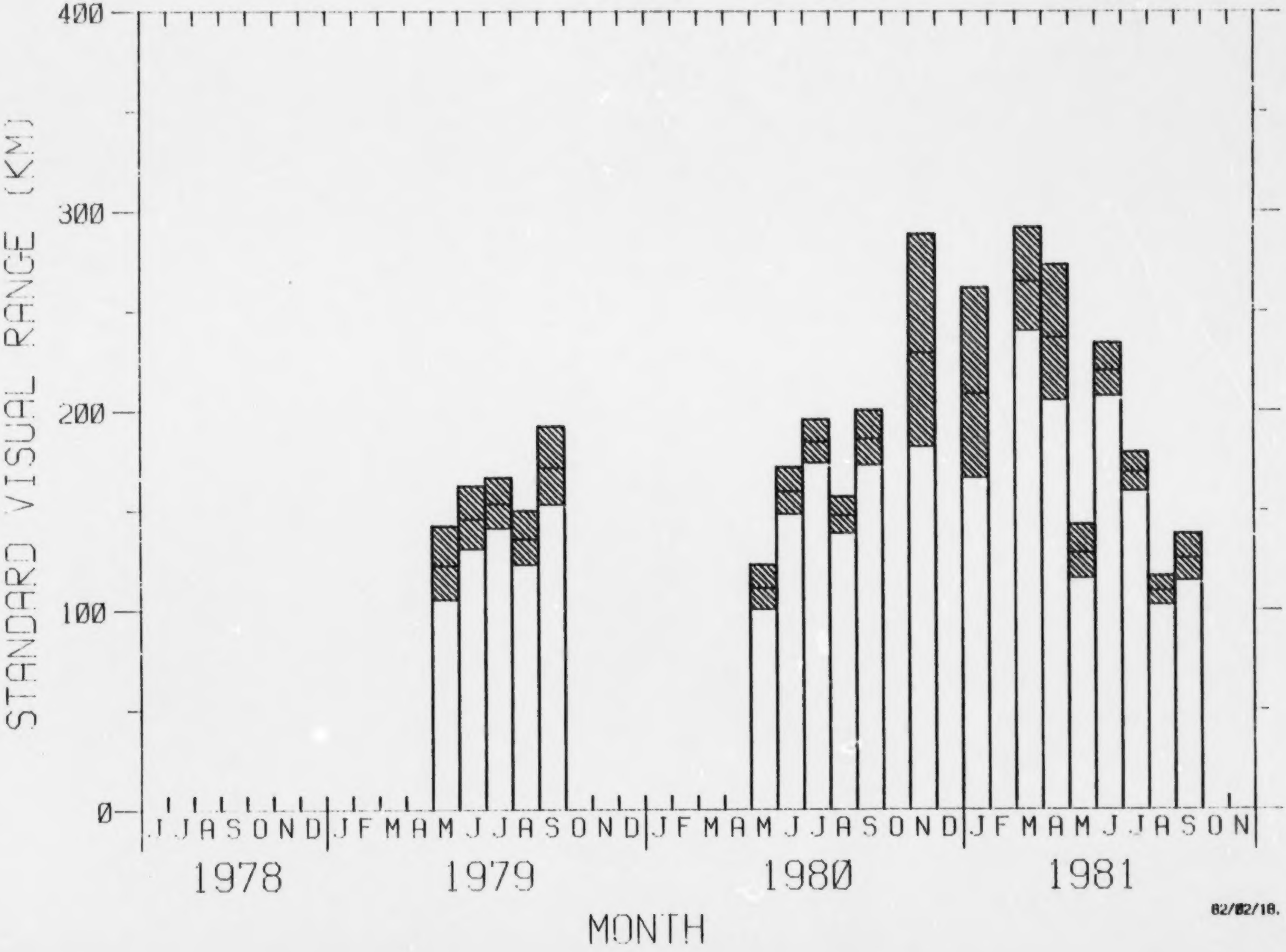
THEODORE ROOSEVELT NATIONAL PARK

MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN



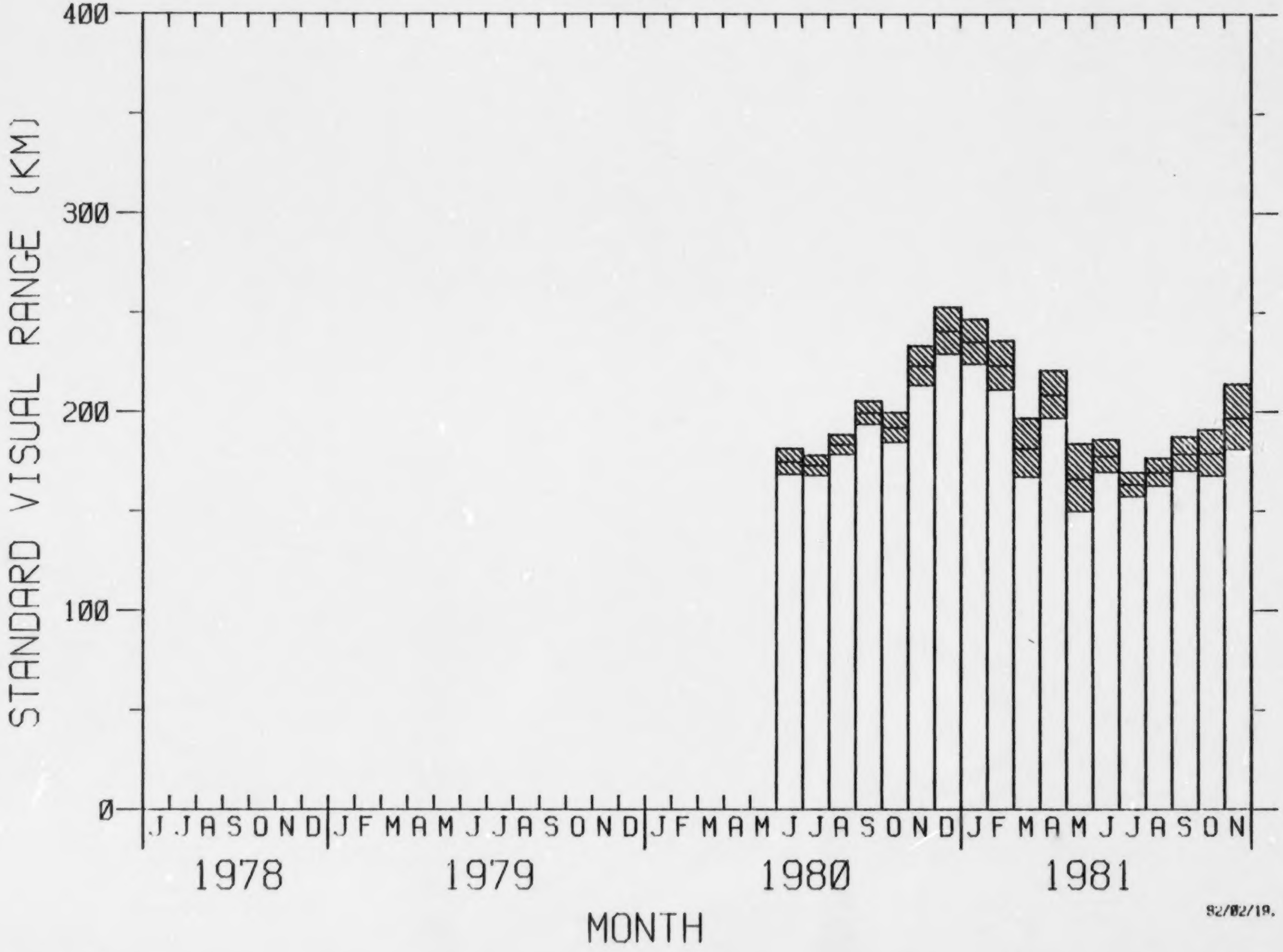
WIND CAVE NATIONAL PARK

MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN



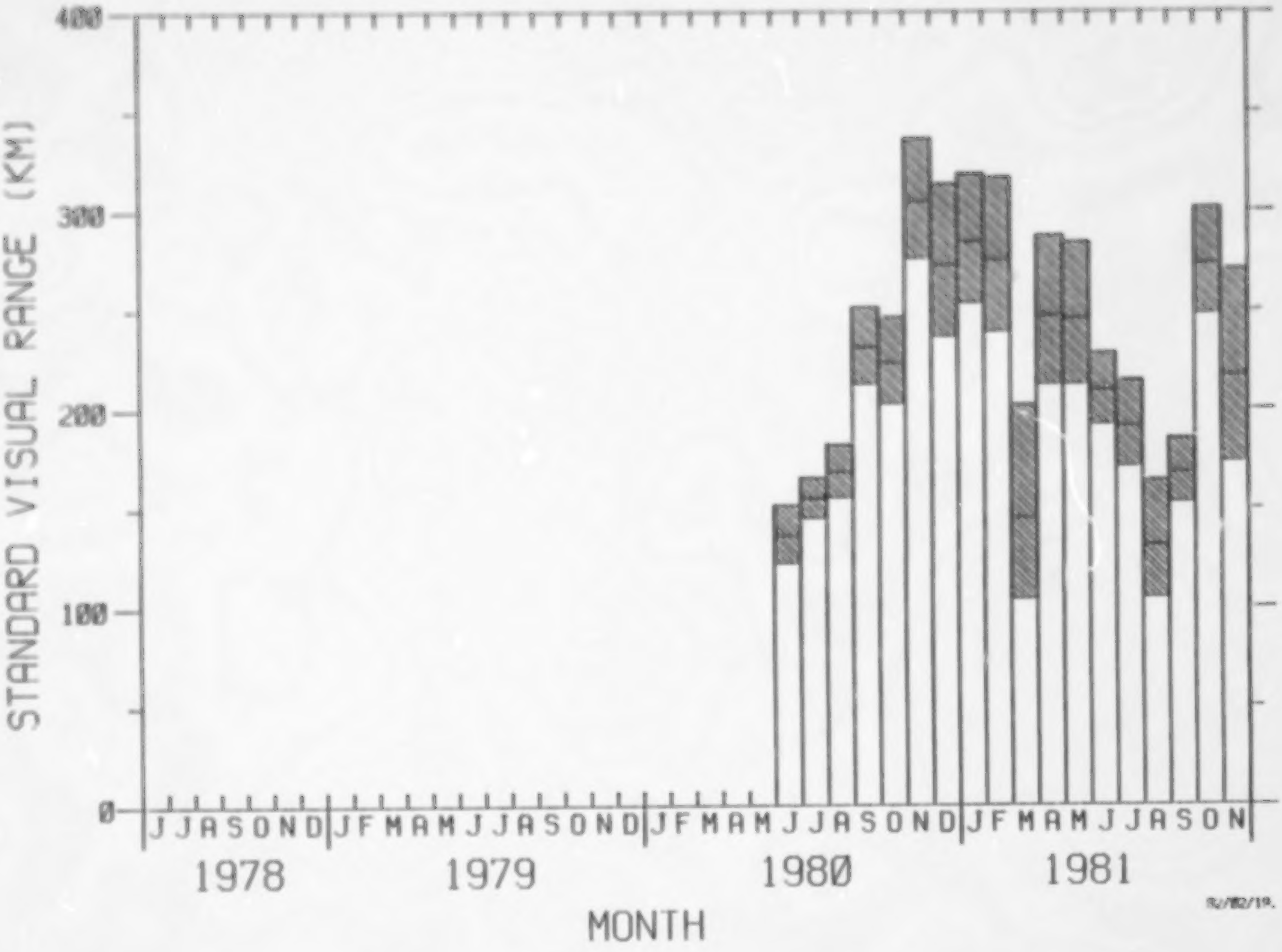
COLORADO NATIONAL MONUMENT

MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN



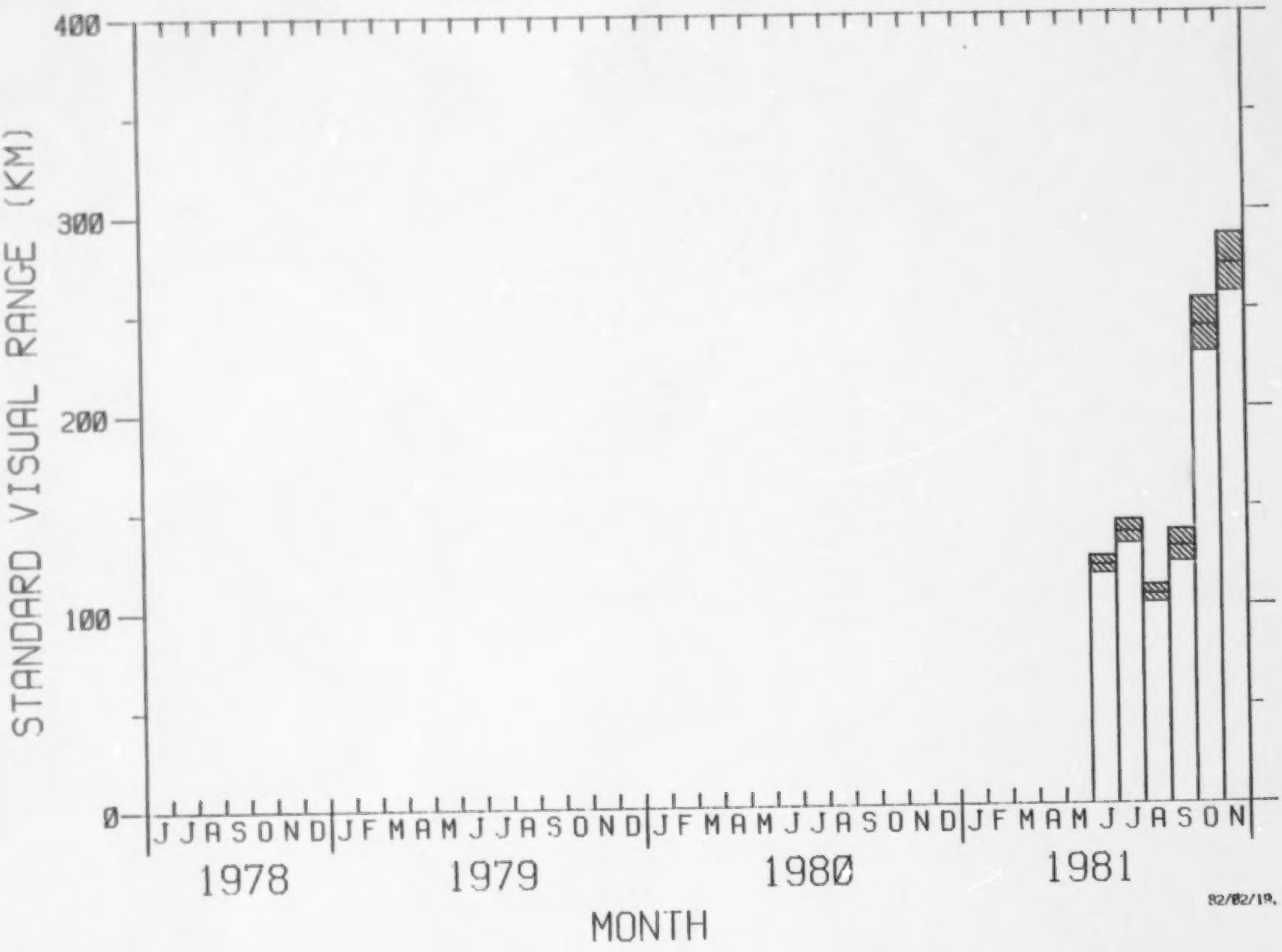
ROCKY MT. NATIONAL PARK

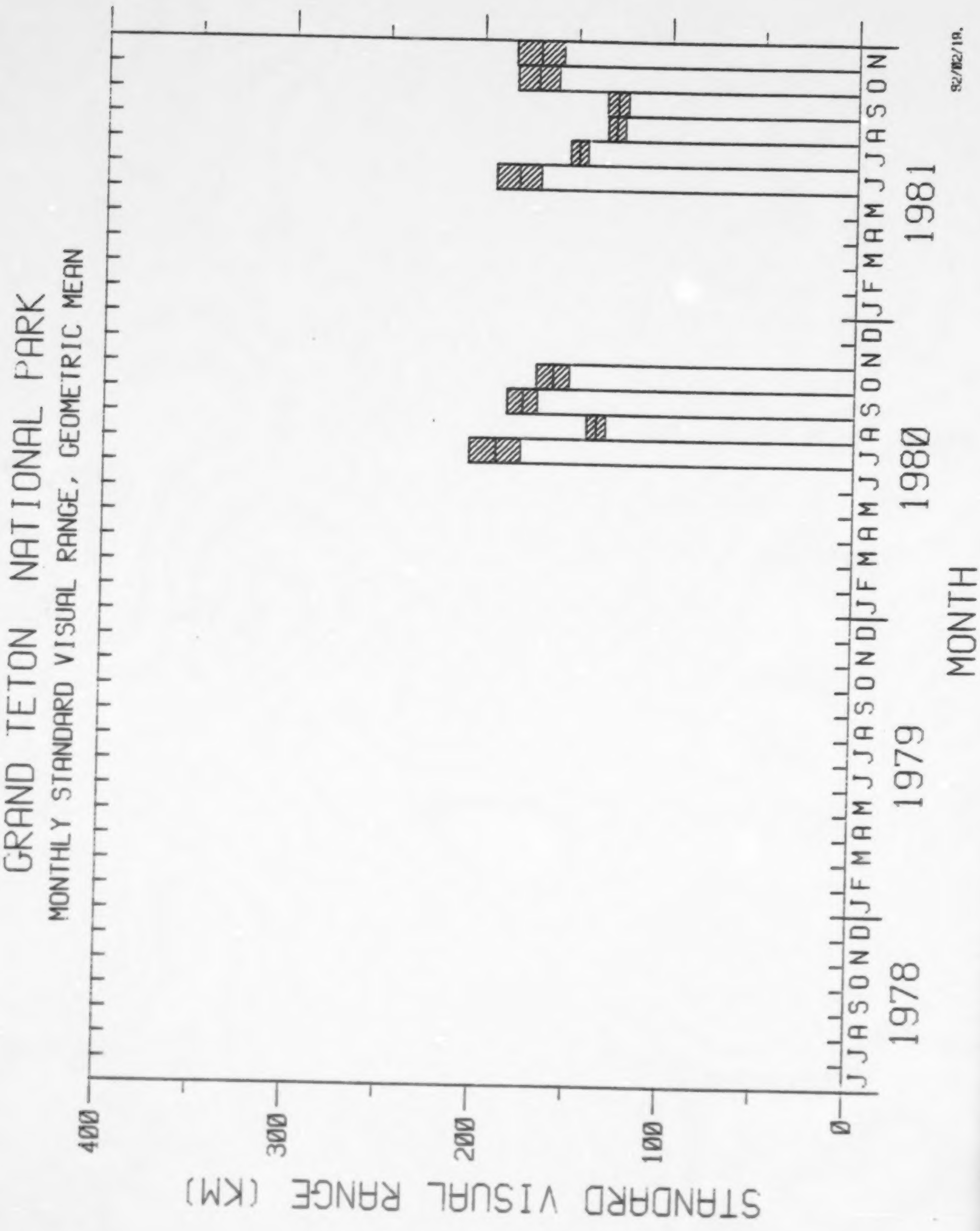
MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN



CHIRICAHUA NATIONAL MONUMENT

MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN



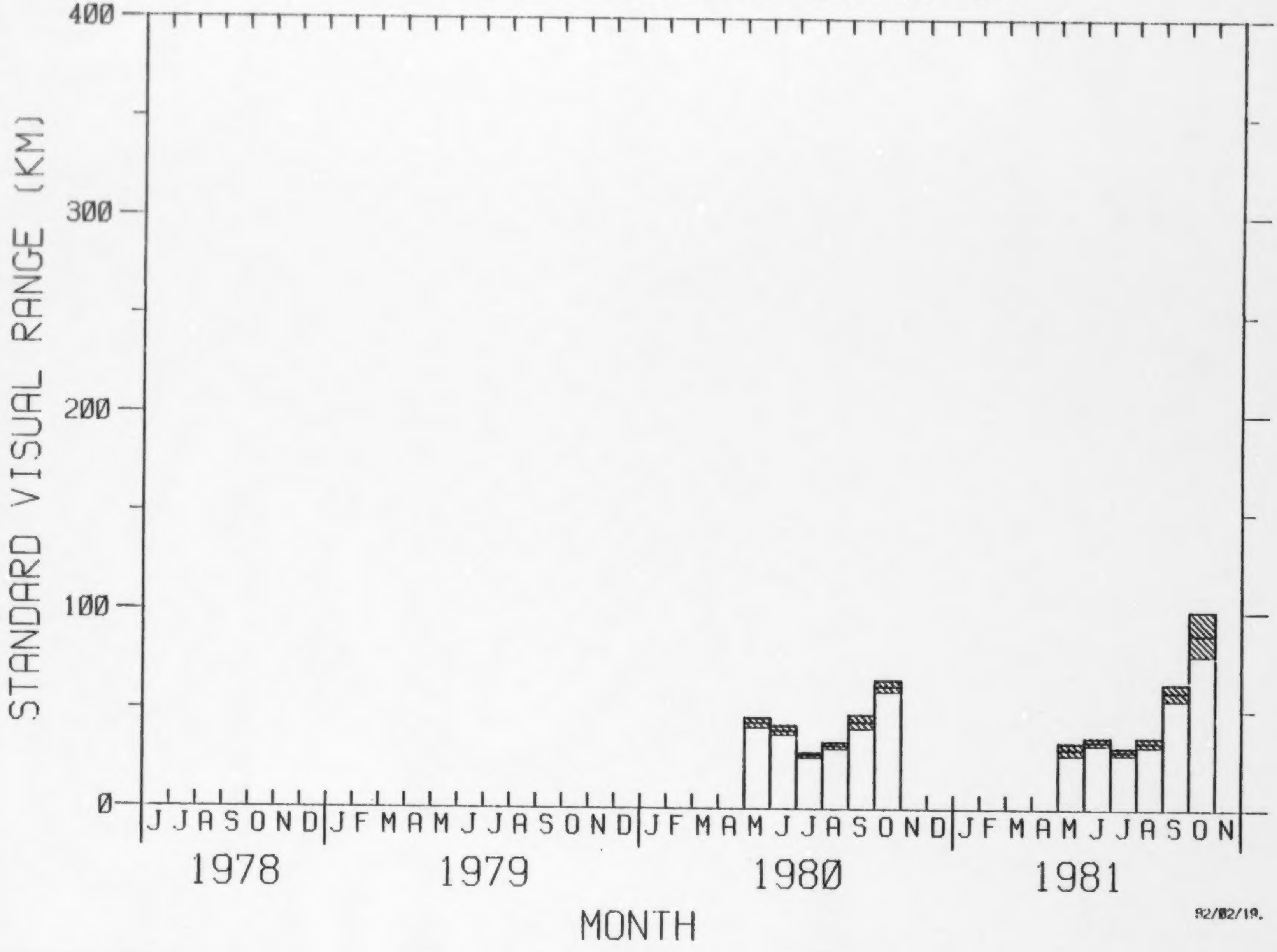


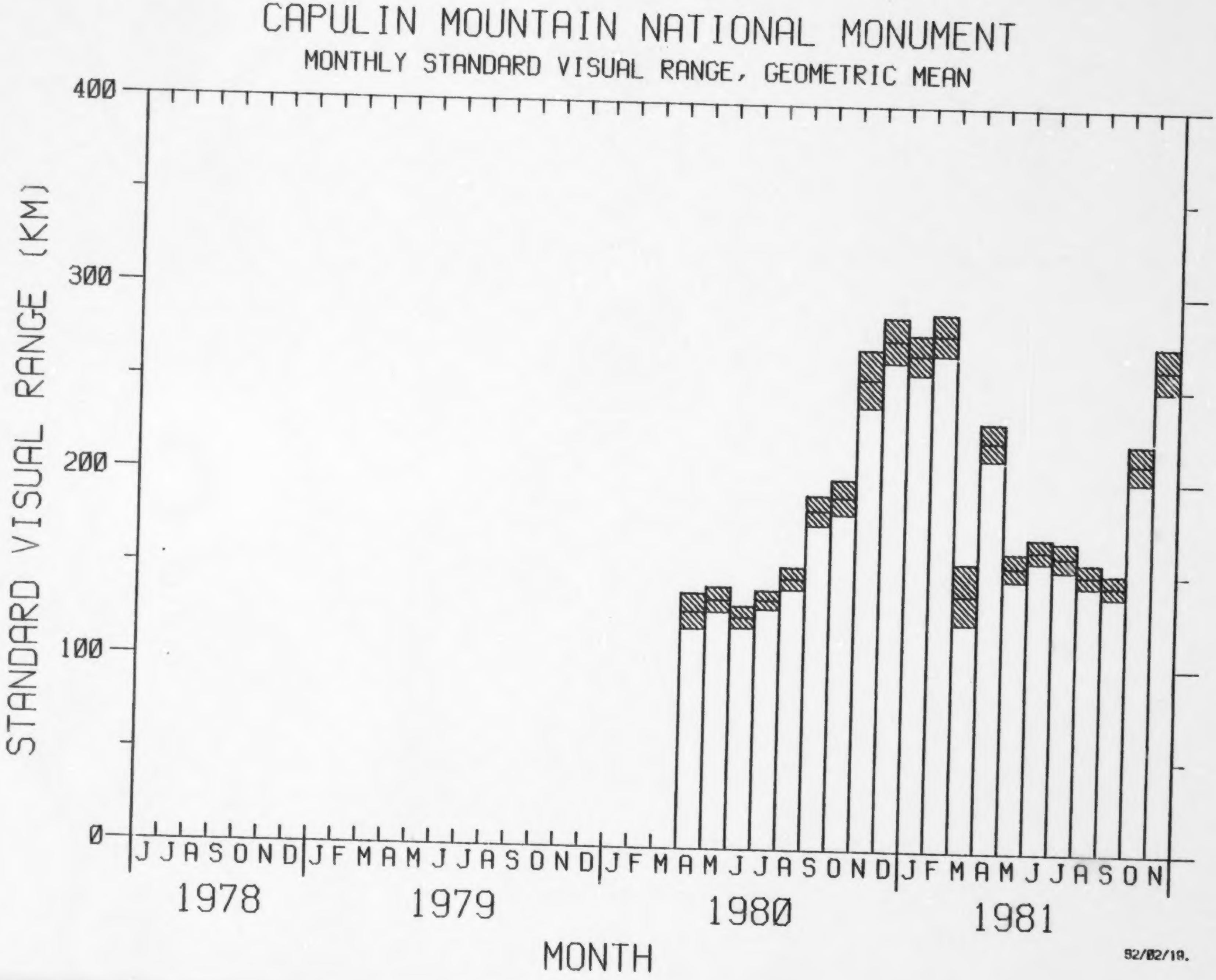
GRAND TETON NATIONAL PARK

MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN

SHENANDOAH NATIONAL PARK

MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN

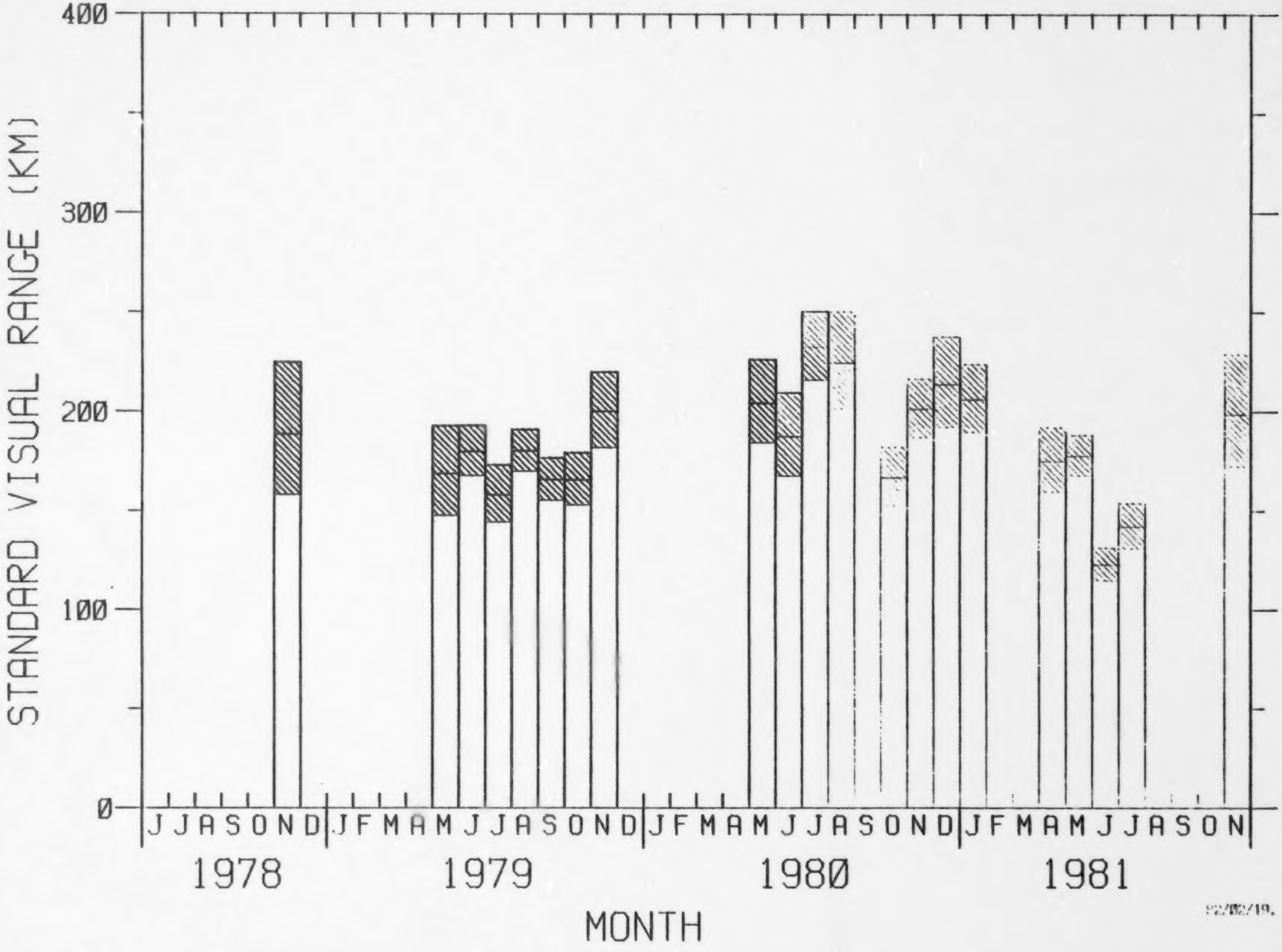




CAPULIN MOUNTAIN NATIONAL MONUMENT
MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN

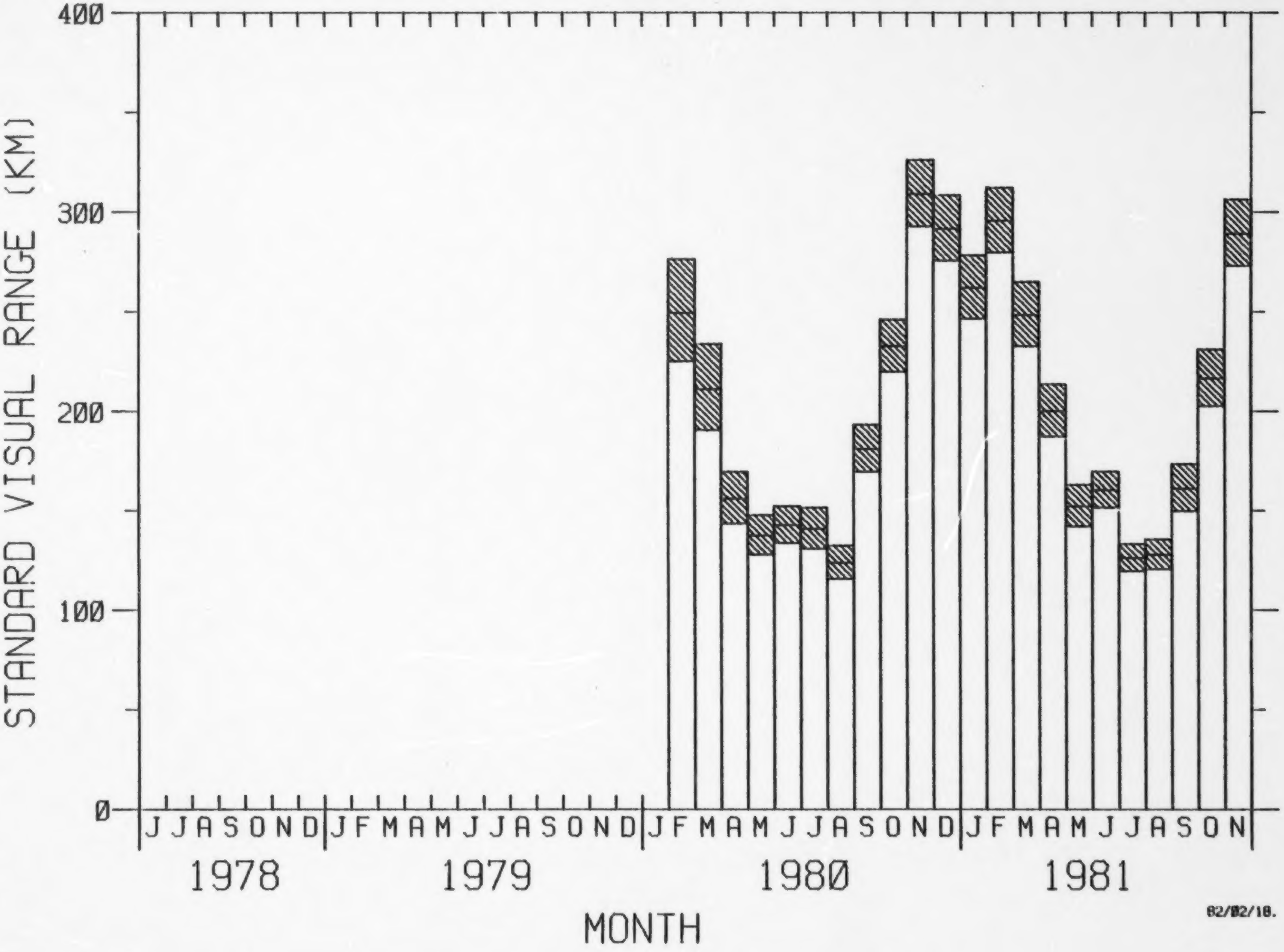
TARGET 6 CHACO CANYON NATIONAL CULTURAL PARK

MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN



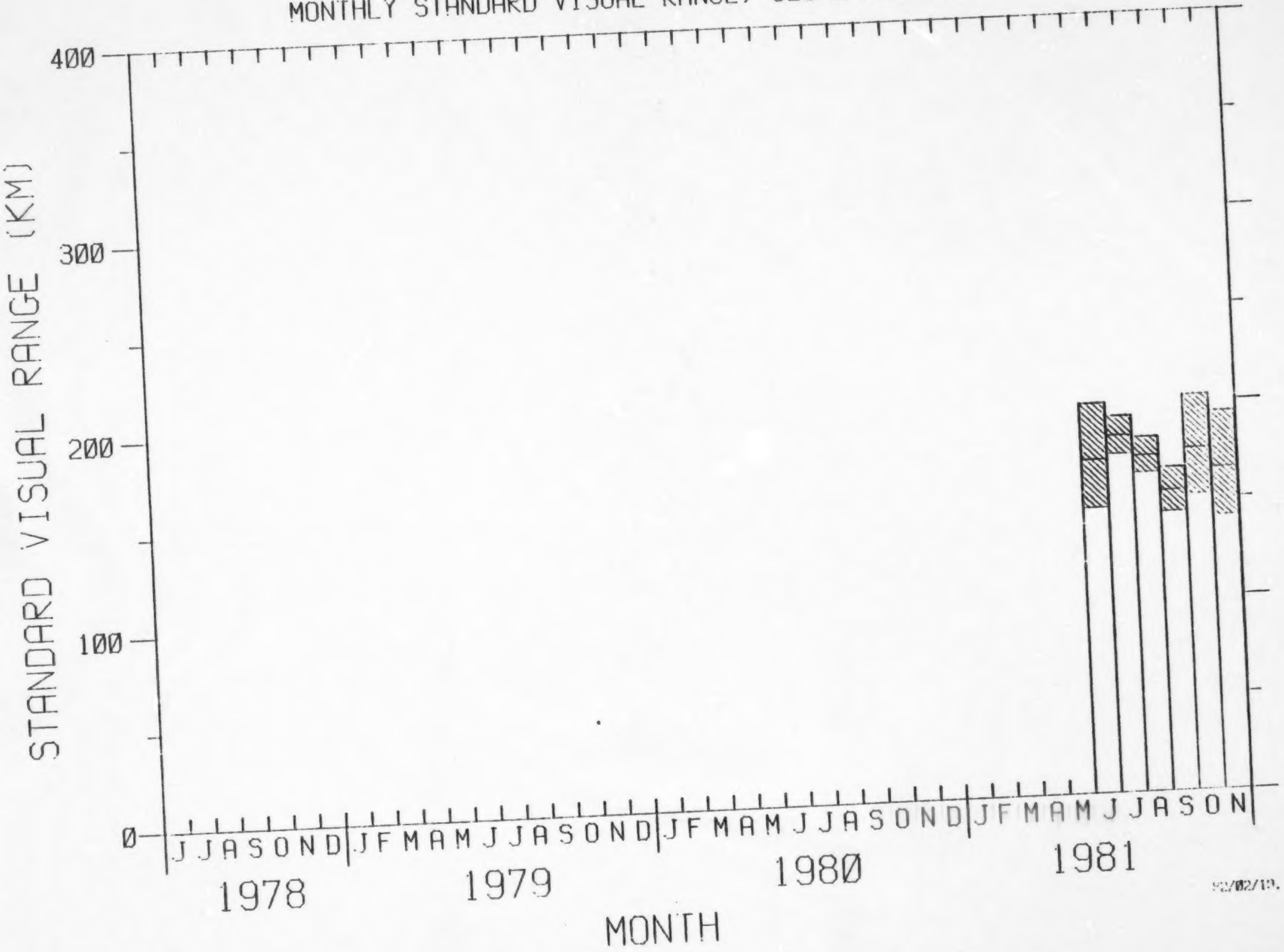
DEATH VALLEY NATIONAL MONUMENT

MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN



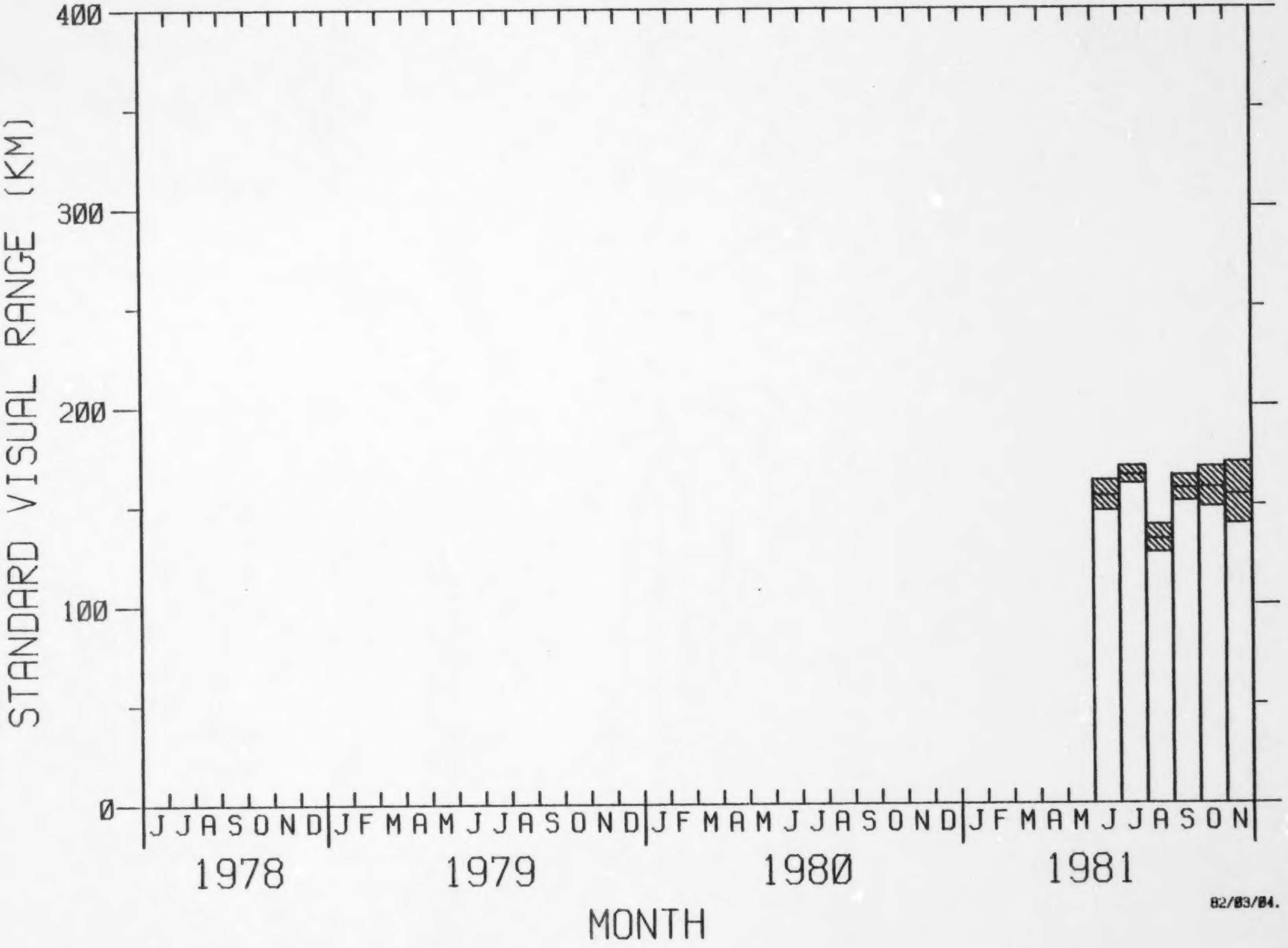
YELLOWSTONE NATIONAL PARK

MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN



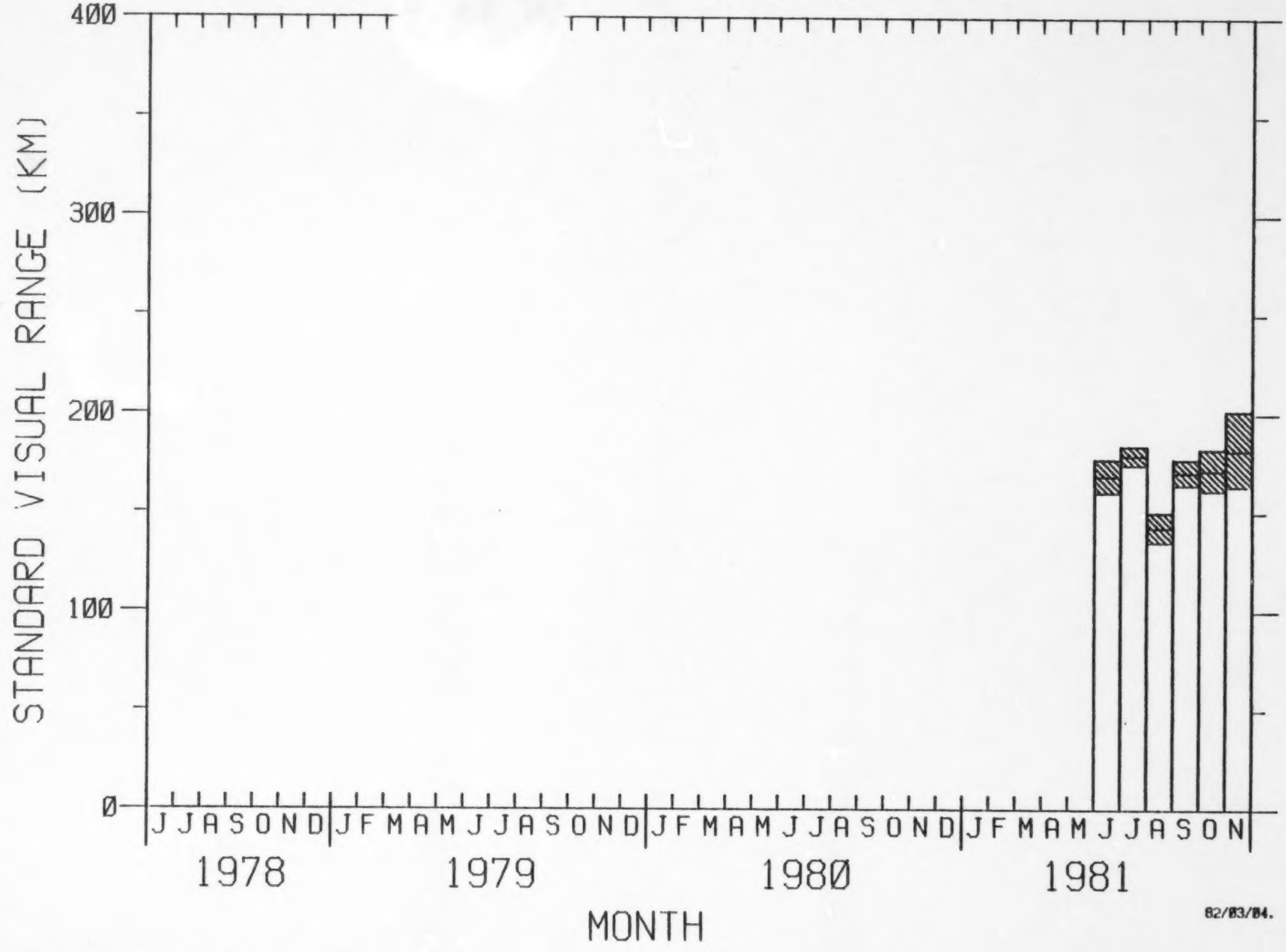
TAHOE LOW

MONTHLY STANDARD VISUAL RANGE, GEOMETRIC MEAN



TAHOE HIGH

MONTH VISUAL RANGE, GEOMETRIC MEAN



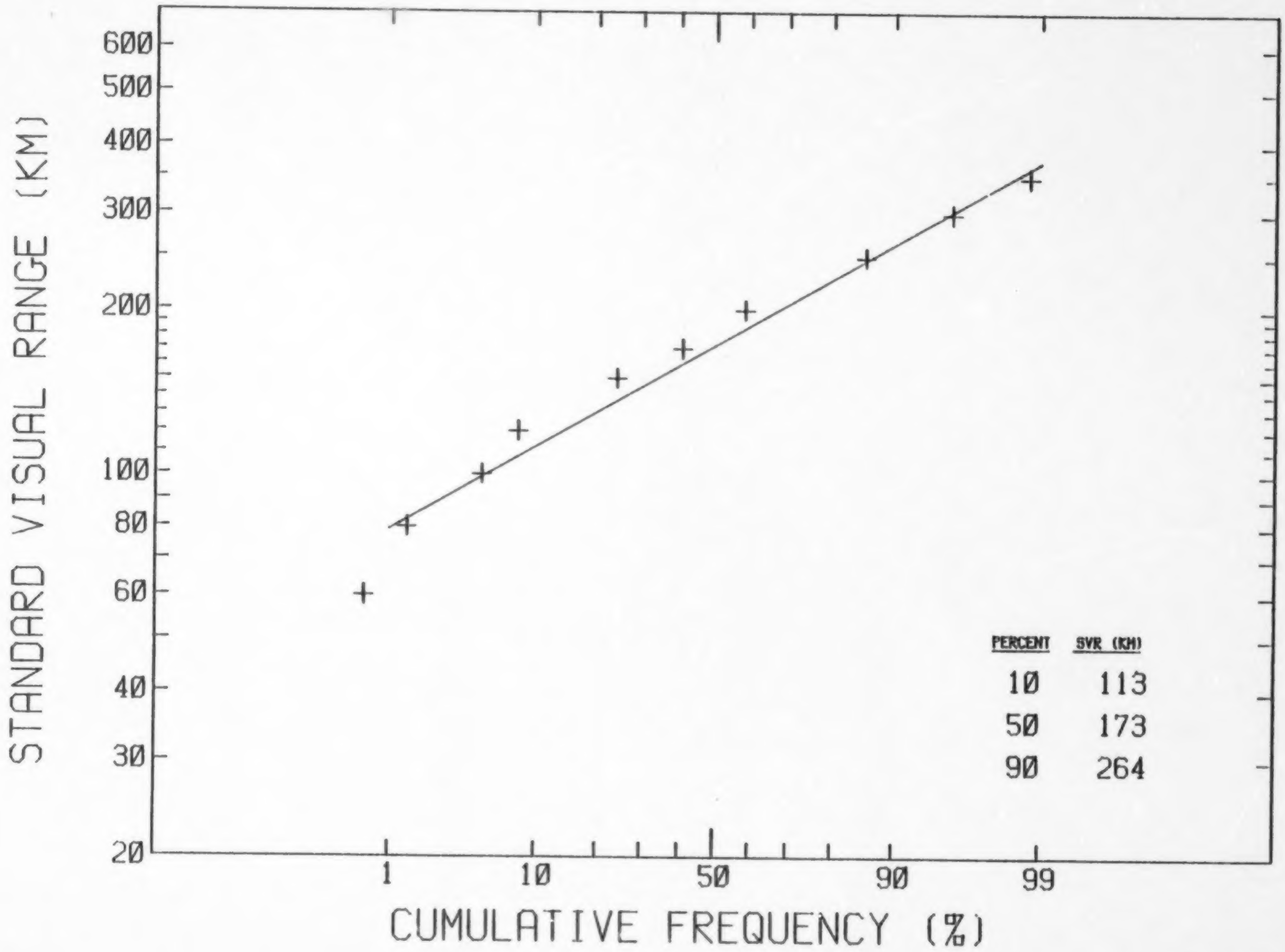
APPENDIX C

CUMULATIVE FREQUENCY DISTRIBUTIONS OF STANDARD VISUAL RANGE

CANYONLANDS NATIONAL PARK, ISLAND IN THE SKY

FROM SEP 78 TO NOV 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE

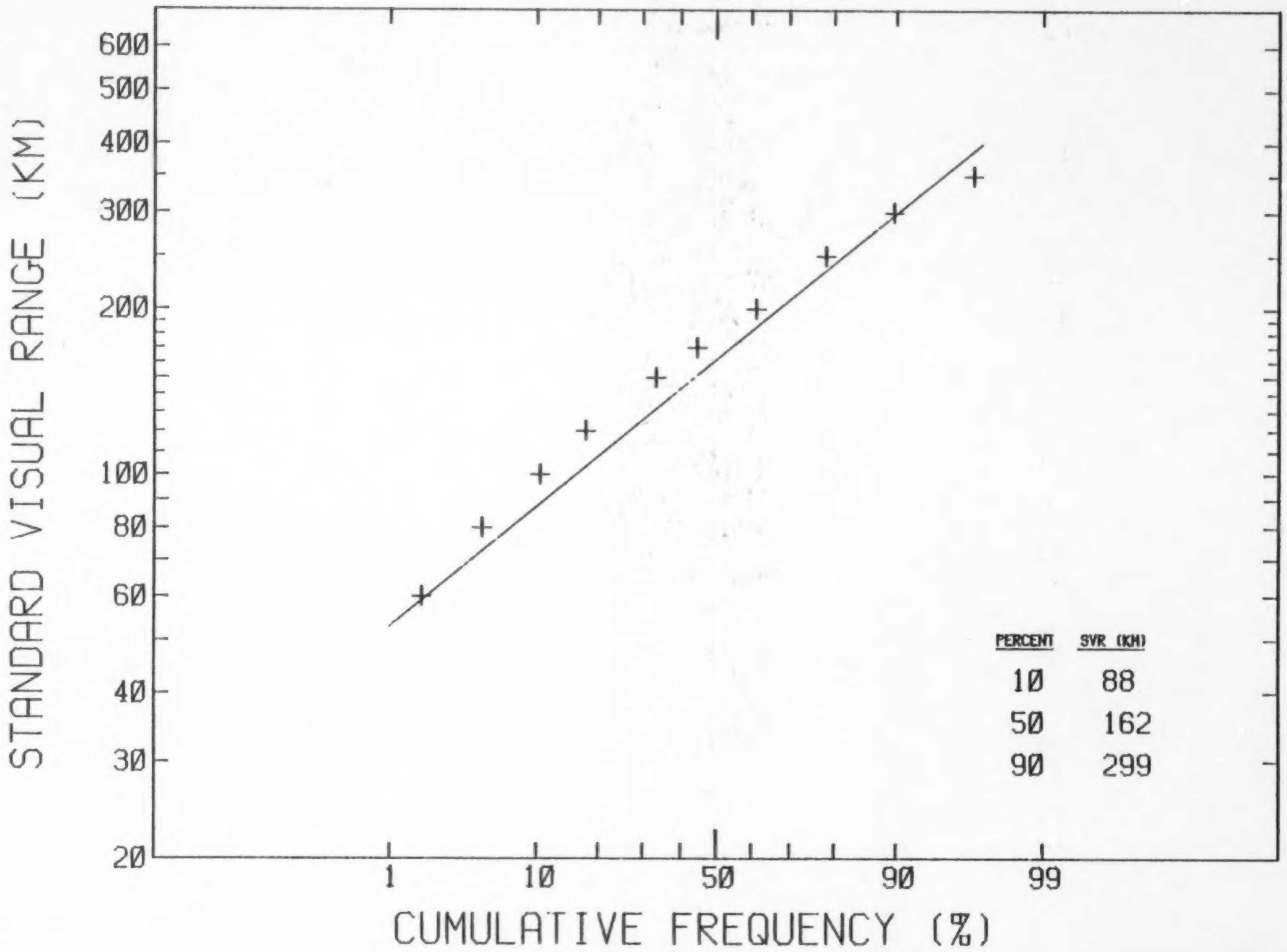


82/03/09.

GRAND CANYON NATIONAL PARK

FROM JUL 78 TO NOV 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE

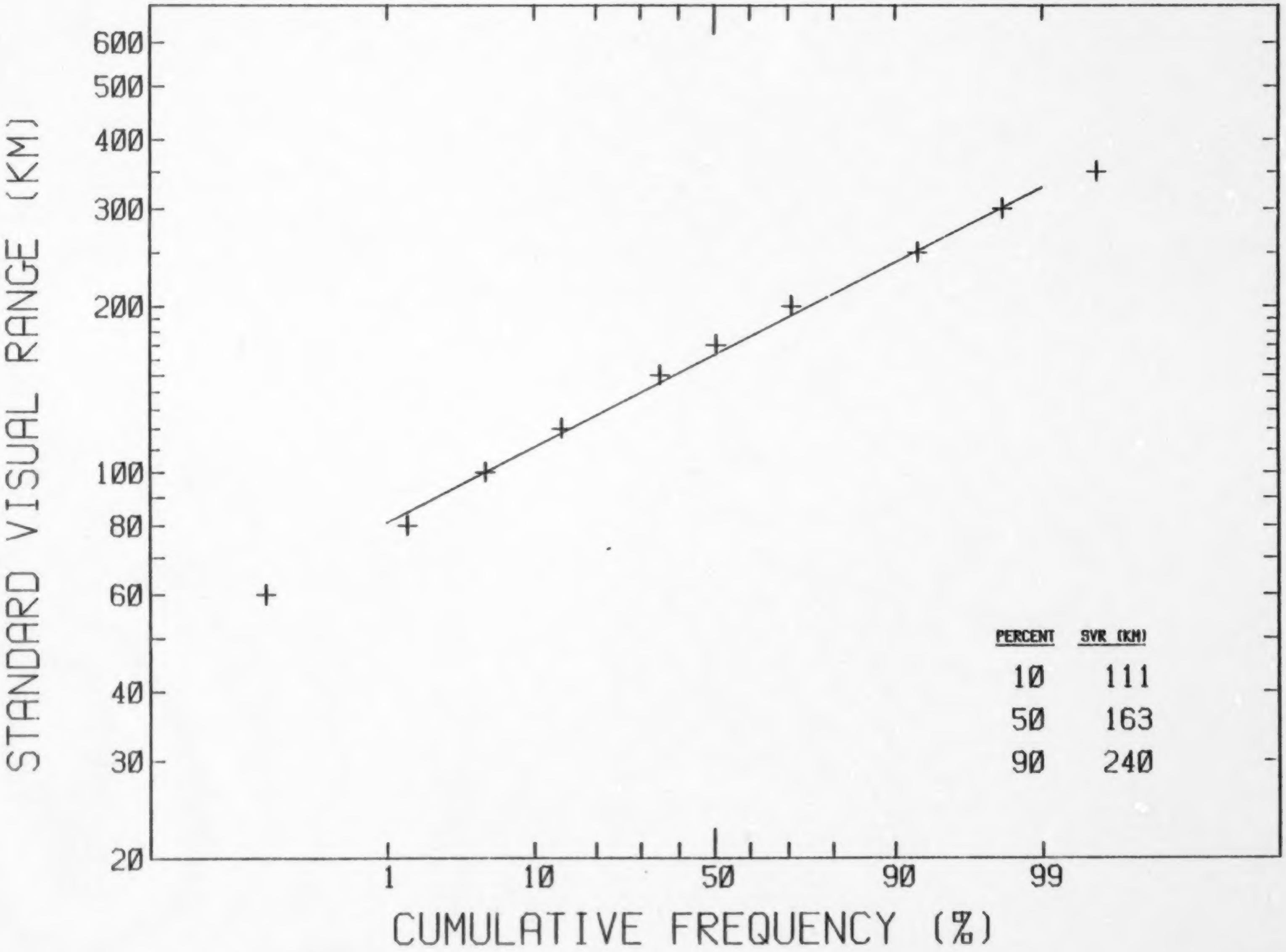


82/03/08.

CANYONLANDS NATIONAL PARK, HANS FLAT

FROM MAR 79 TO FEB 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE



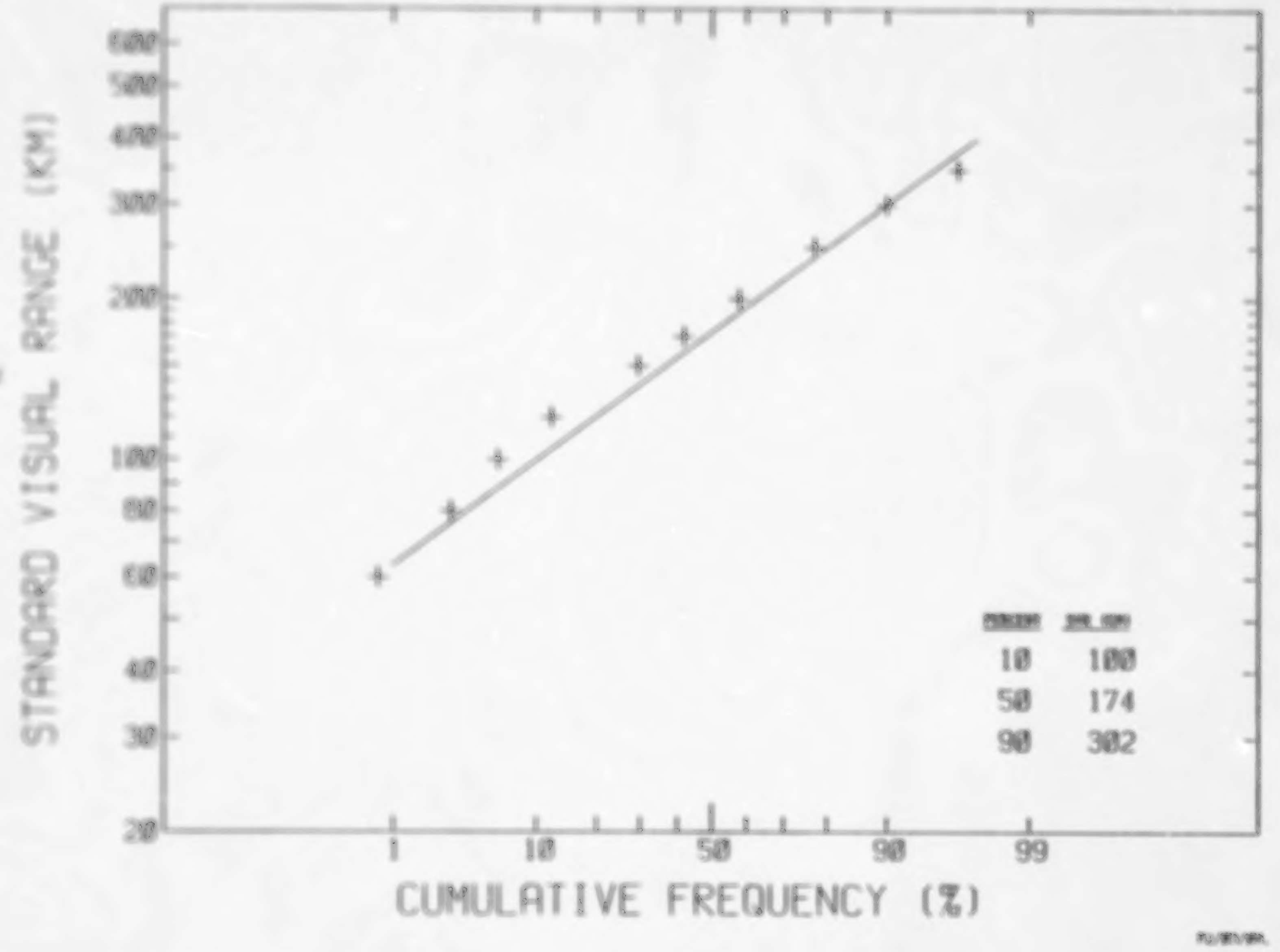
PERCENT	SVR (KM)
10	111
50	163
90	240

82/03/09.

BRYCE CANYON NATIONAL PARK

FROM JUN 78 TO NOV 81

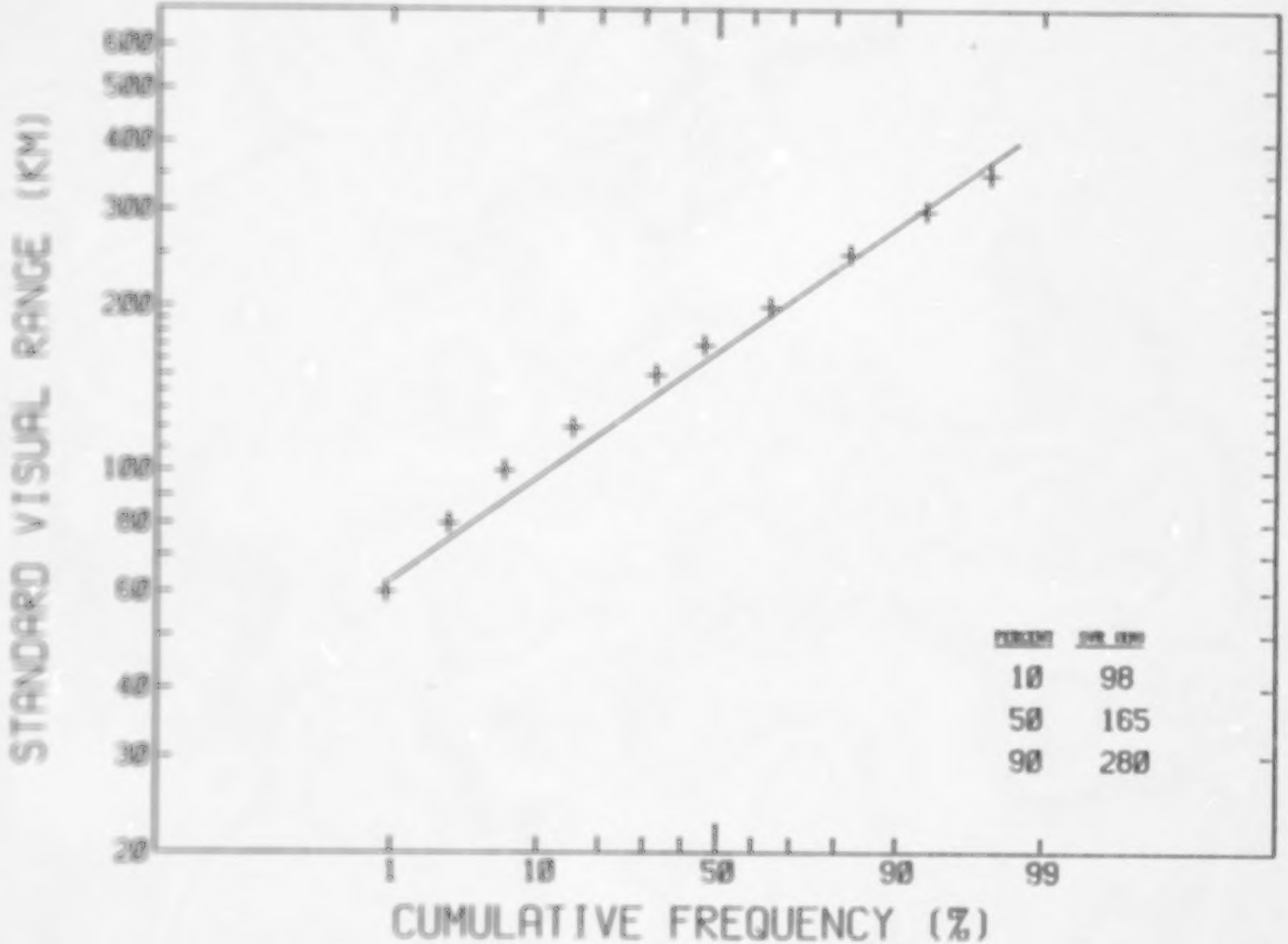
CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE



CAPITOL REEF NATIONAL PARK

FROM JUN 78 TO NOV 81

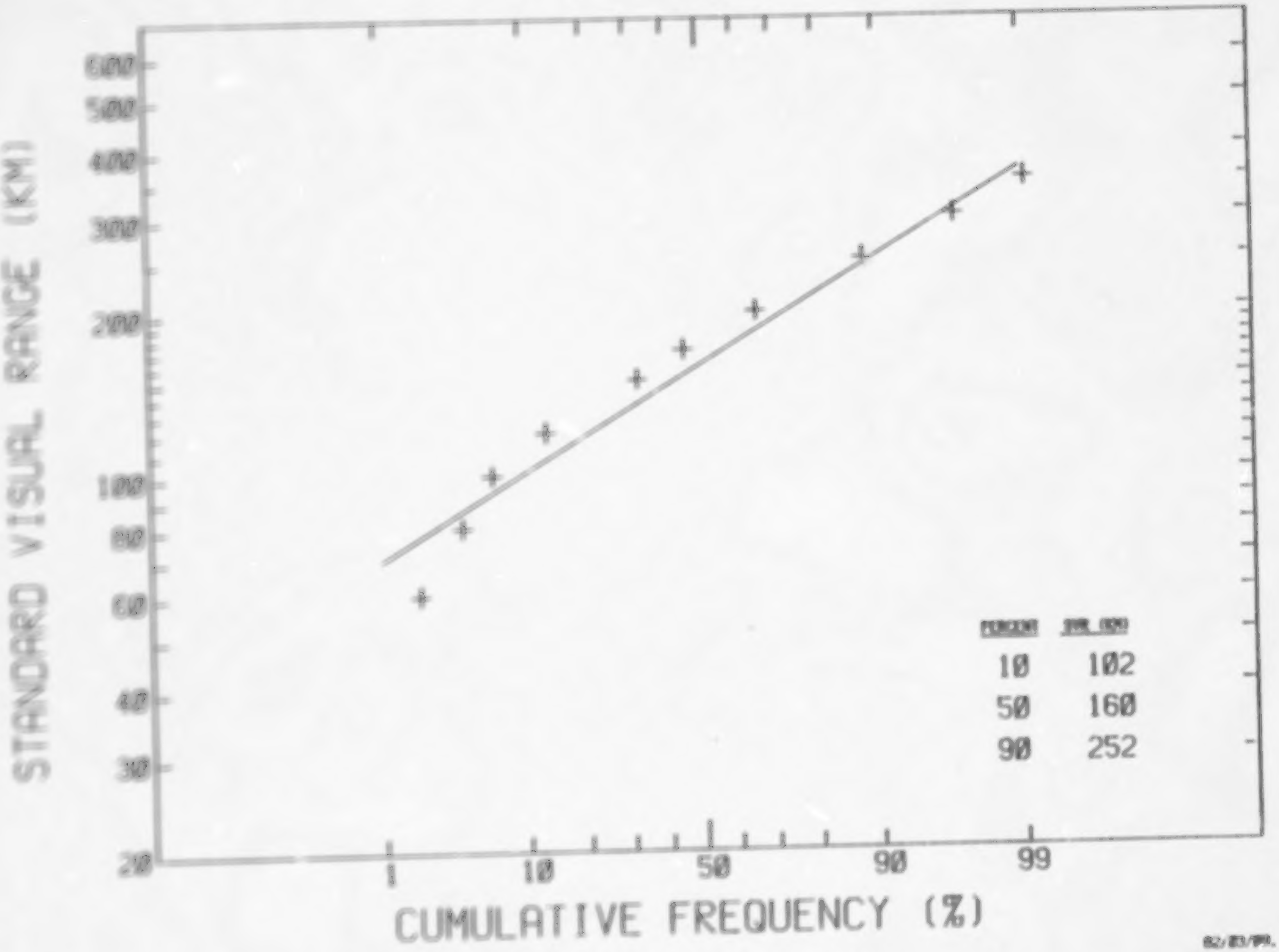
CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE



DINOSAUR NATIONAL MONUMENT

FROM JUL 78 TO AUG 81

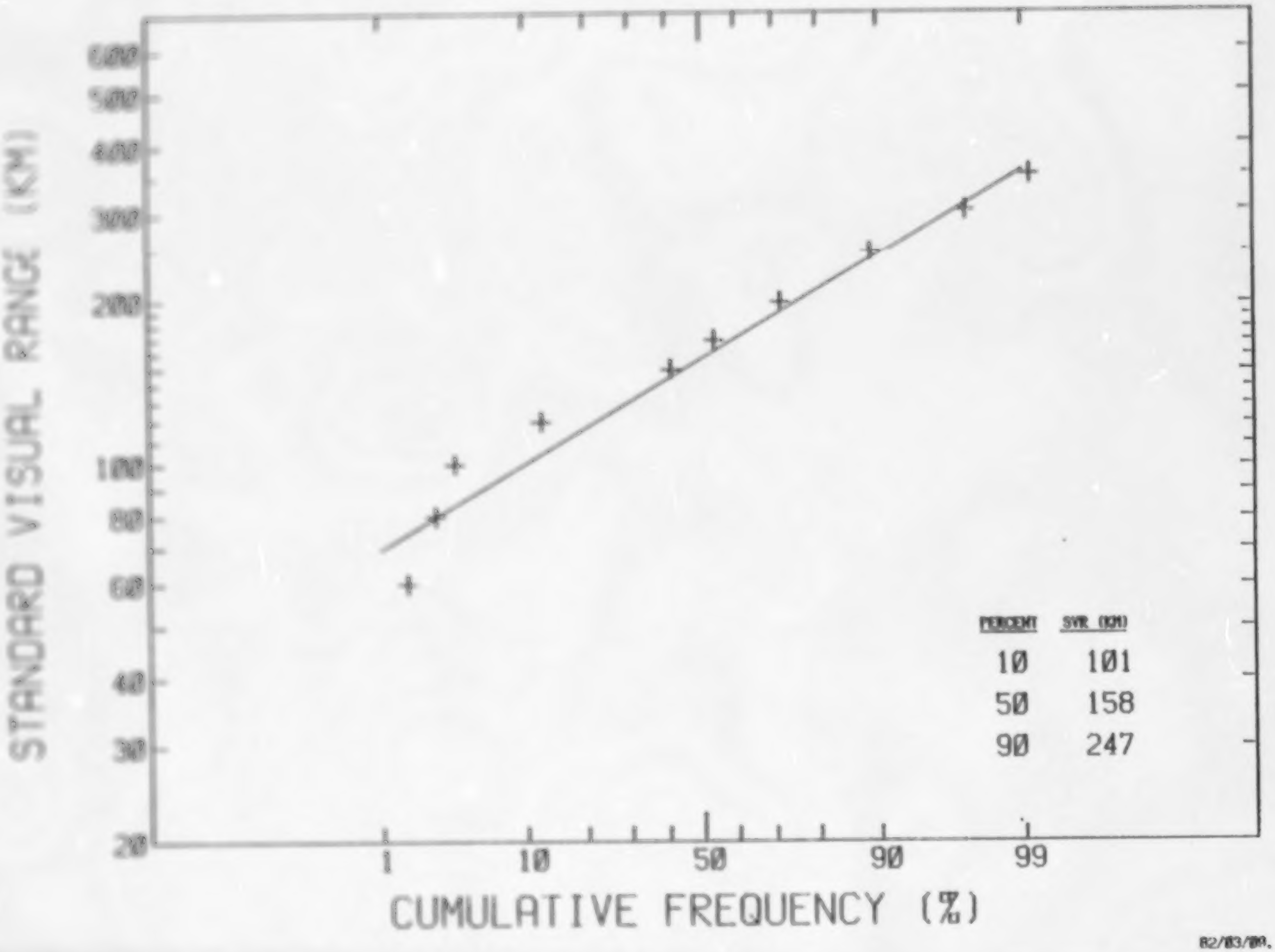
CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE



MESA VERDE NATIONAL PARK

FROM JUL 78 TO NOV 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE



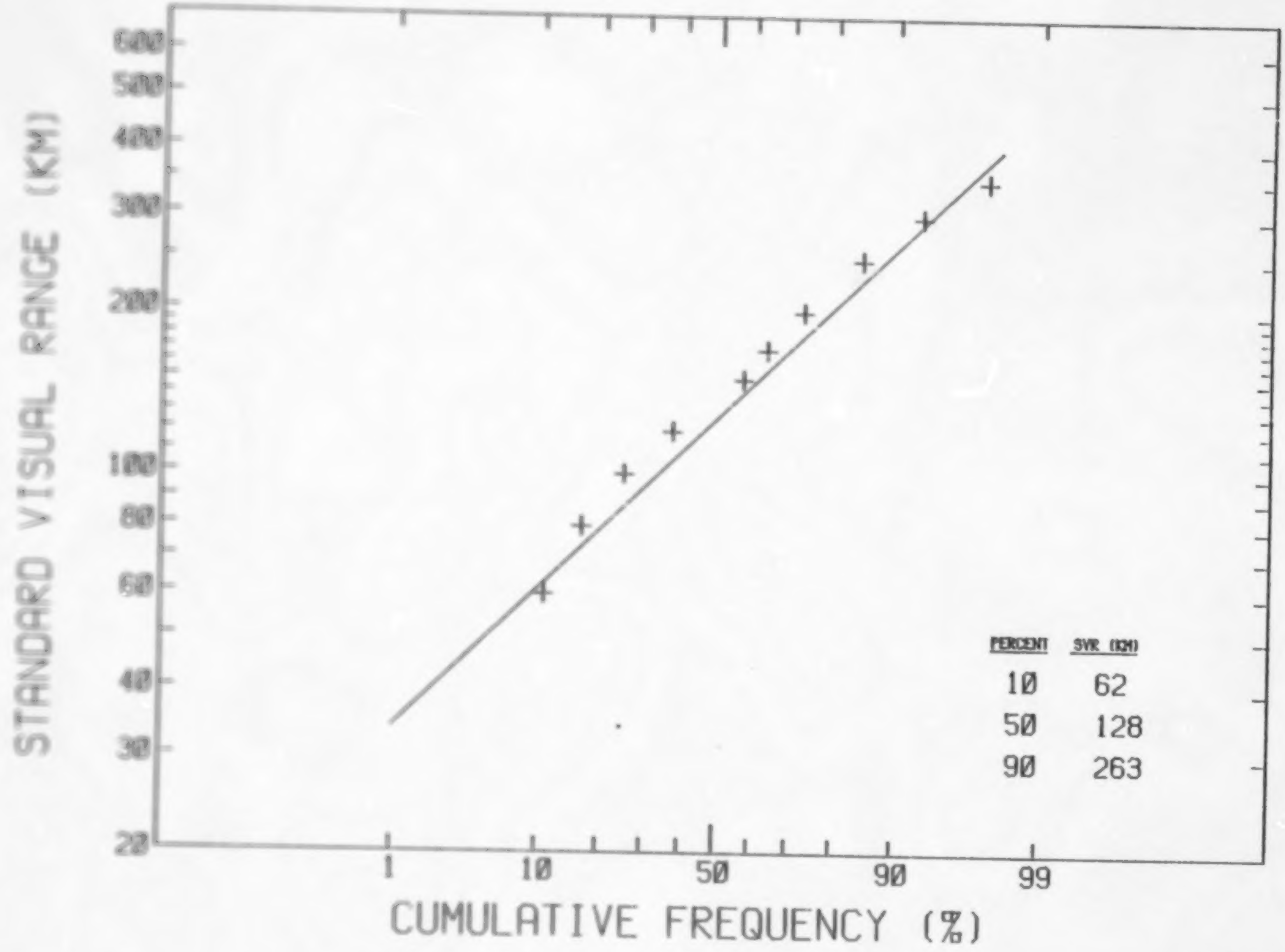
PERCENT	SVR (KM)
10	101
50	158
90	247

82/03/08.

OLYMPIC NATIONAL PARK

FROM APR 80 TO MAY 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE

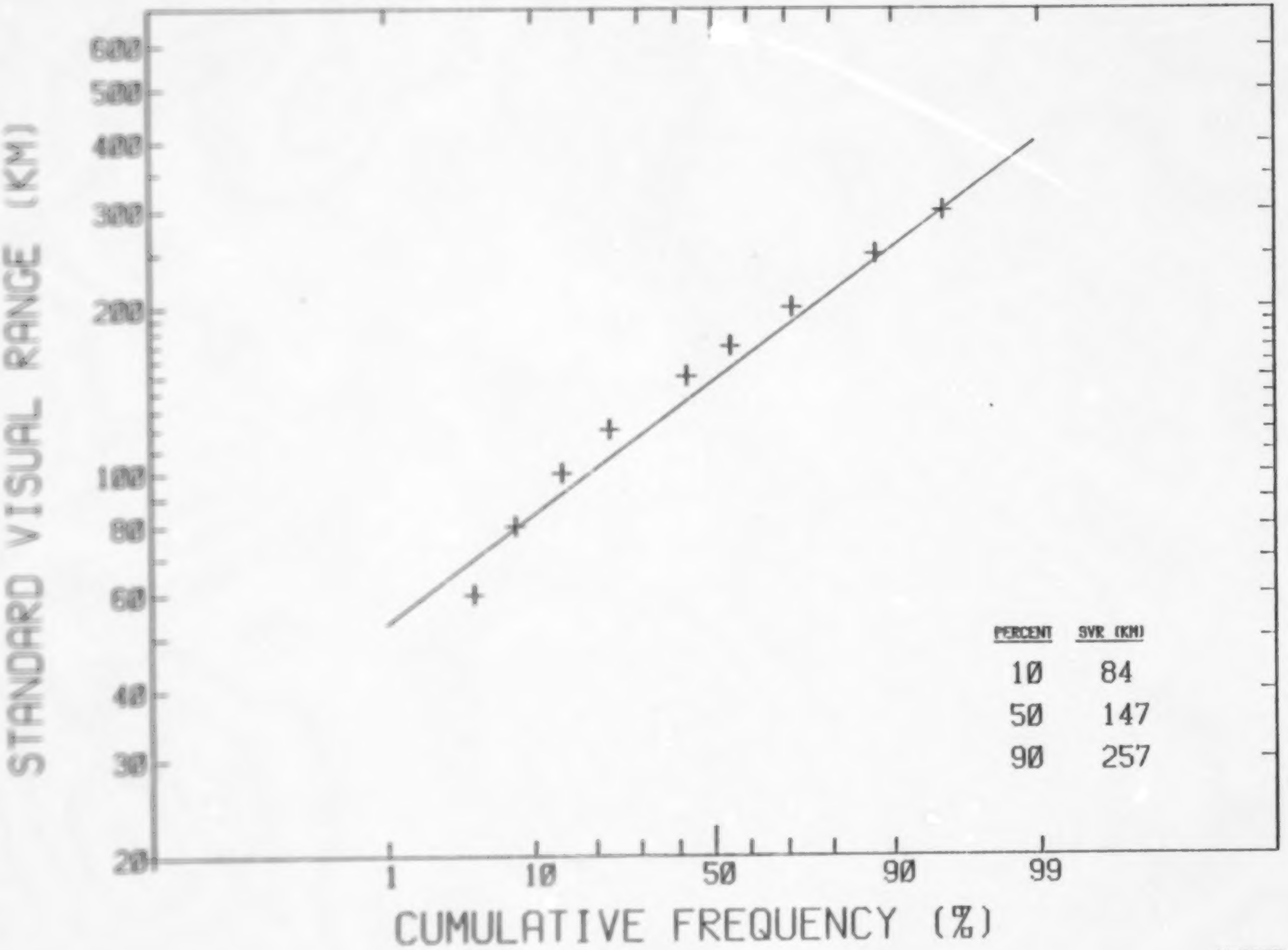


02/03/80.

WUPATKI NATIONAL MONUMENT

FROM AUG 78 TO NOV 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE

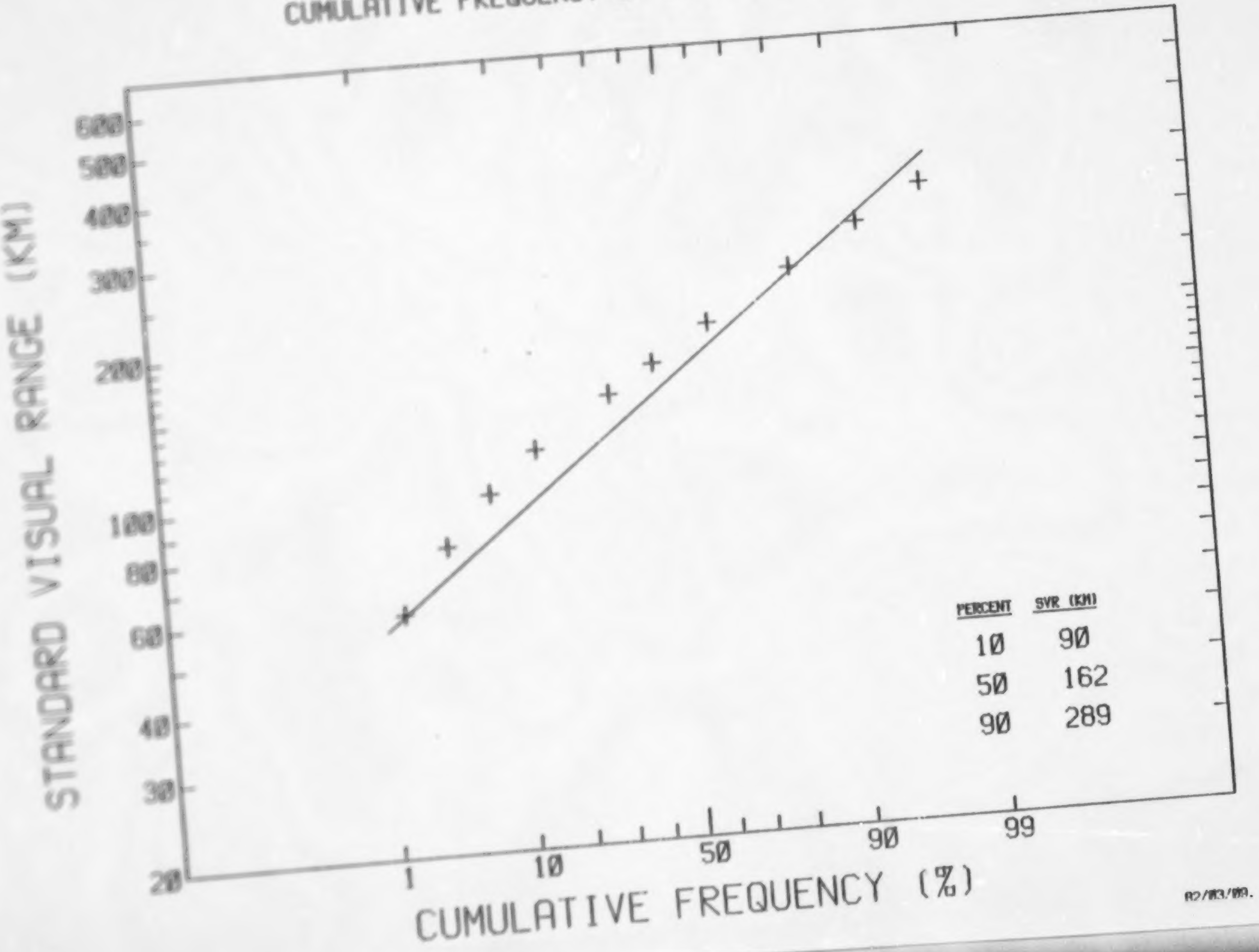


82/03/09.

NAVAJO NATIONAL MONUMENT

FROM AUG 78 TO NOV 81

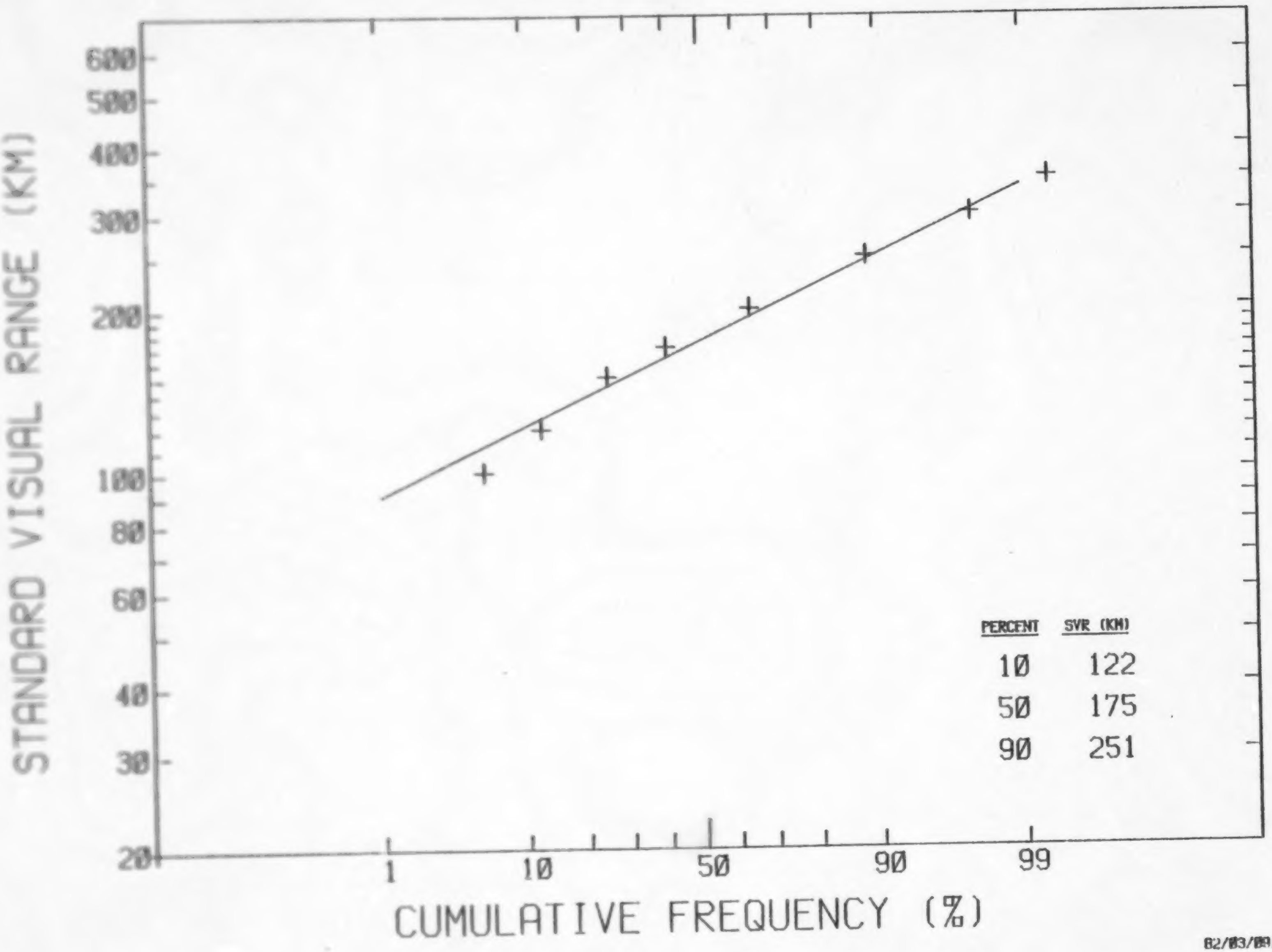
CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE



CHACO CANYON NATIONAL CULTURAL PARK

FROM JUL 78 TO NOV 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE

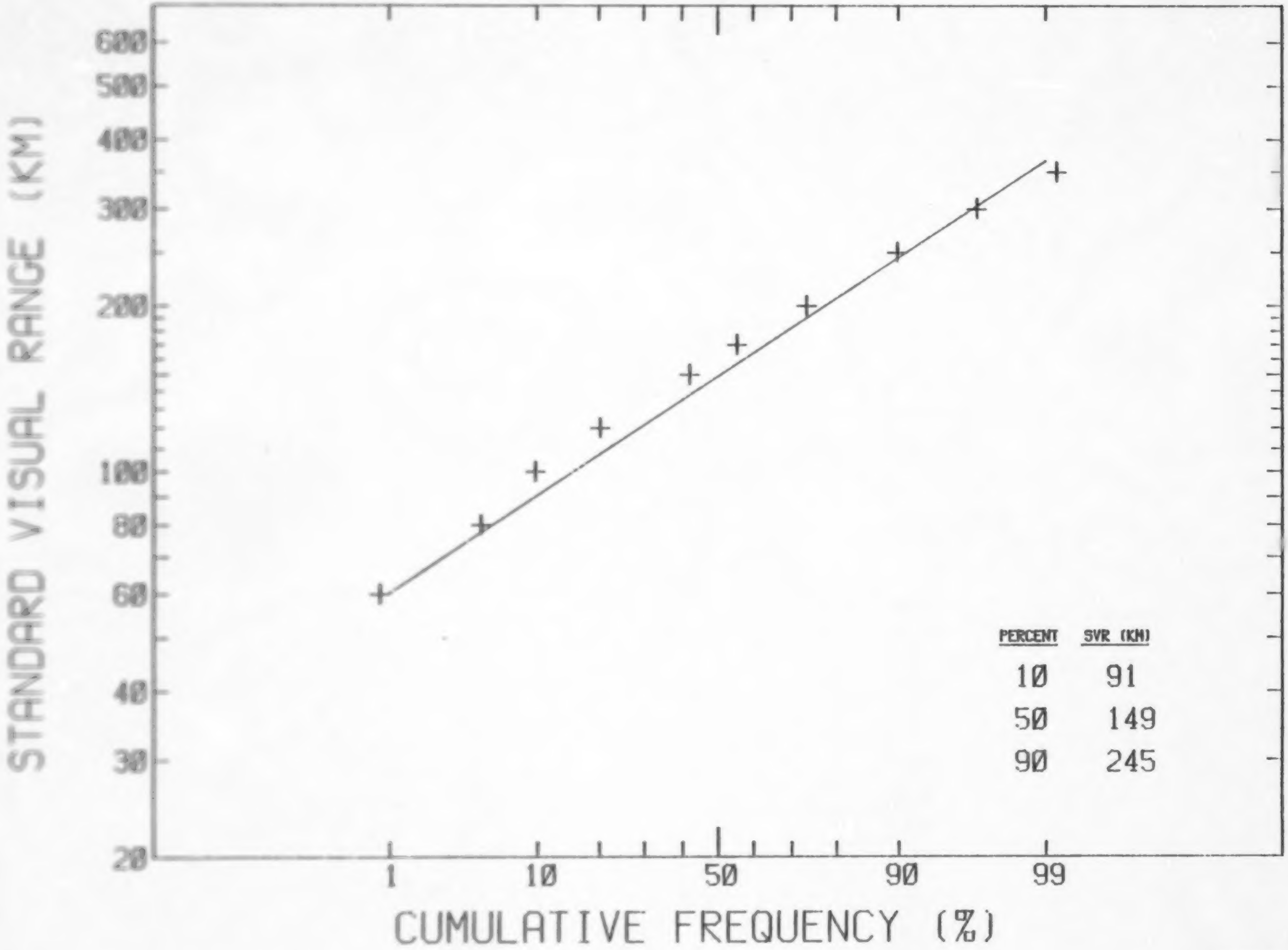


82/03/09.

BANDELIER NATIONAL MONUMENT

FROM JUL 78 TO NOV 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE

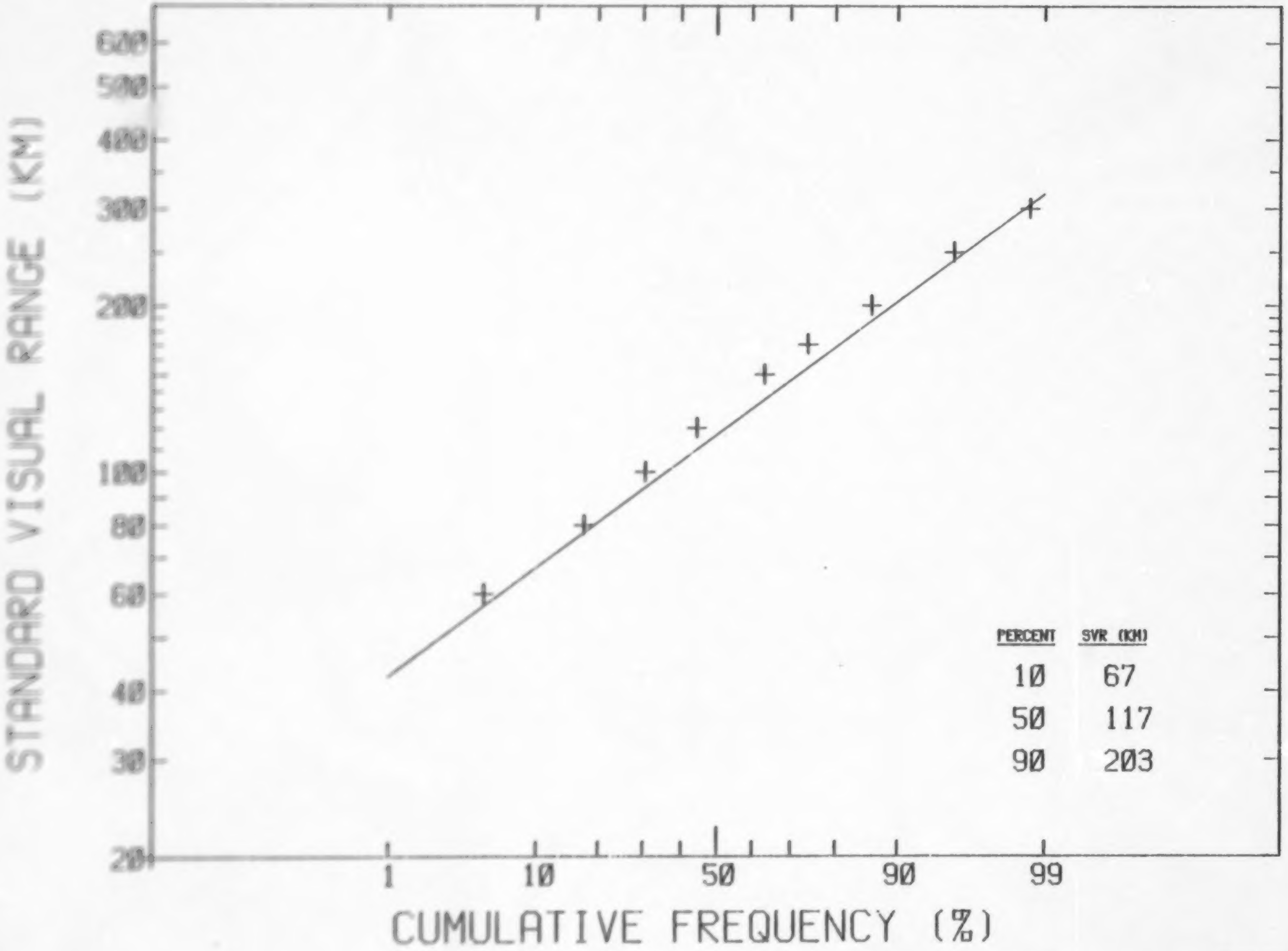


82/03/10.

WHITE SANDS NATIONAL MONUMENT

FROM JUL 78 TO NOV 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE



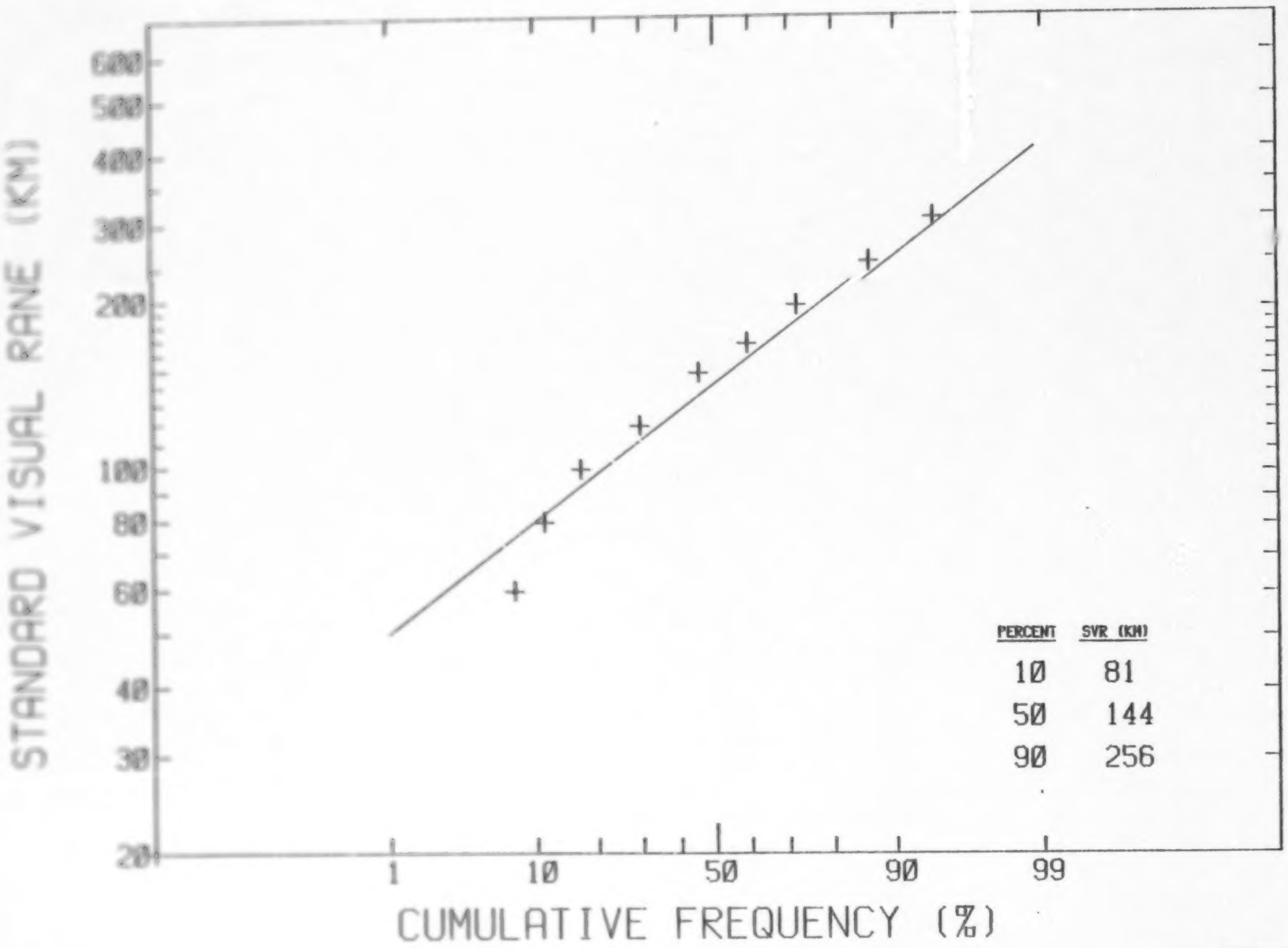
PERCENT	SVR (KM)
10	67
50	117
90	203

82/03/10.

CARLSBAD CAVERNS NATIONAL PARK

FROM JUL 78 TO APR 80

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE



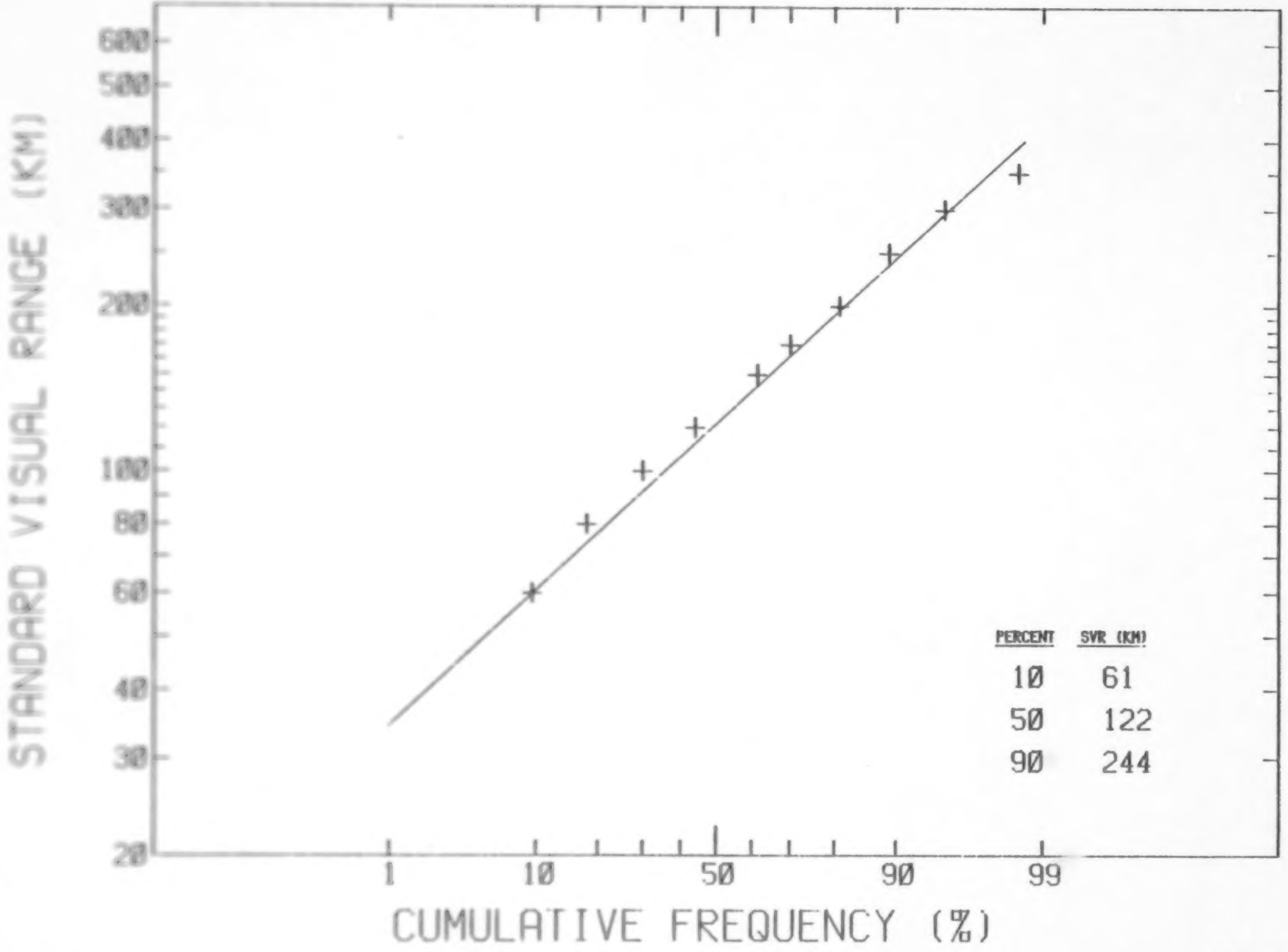
PERCENT	SVR (KM)
10	81
50	144
90	256

82/03/10.

THEODORE ROOSEVELT NATIONAL PARK

FROM FEB 79 TO NOV 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE

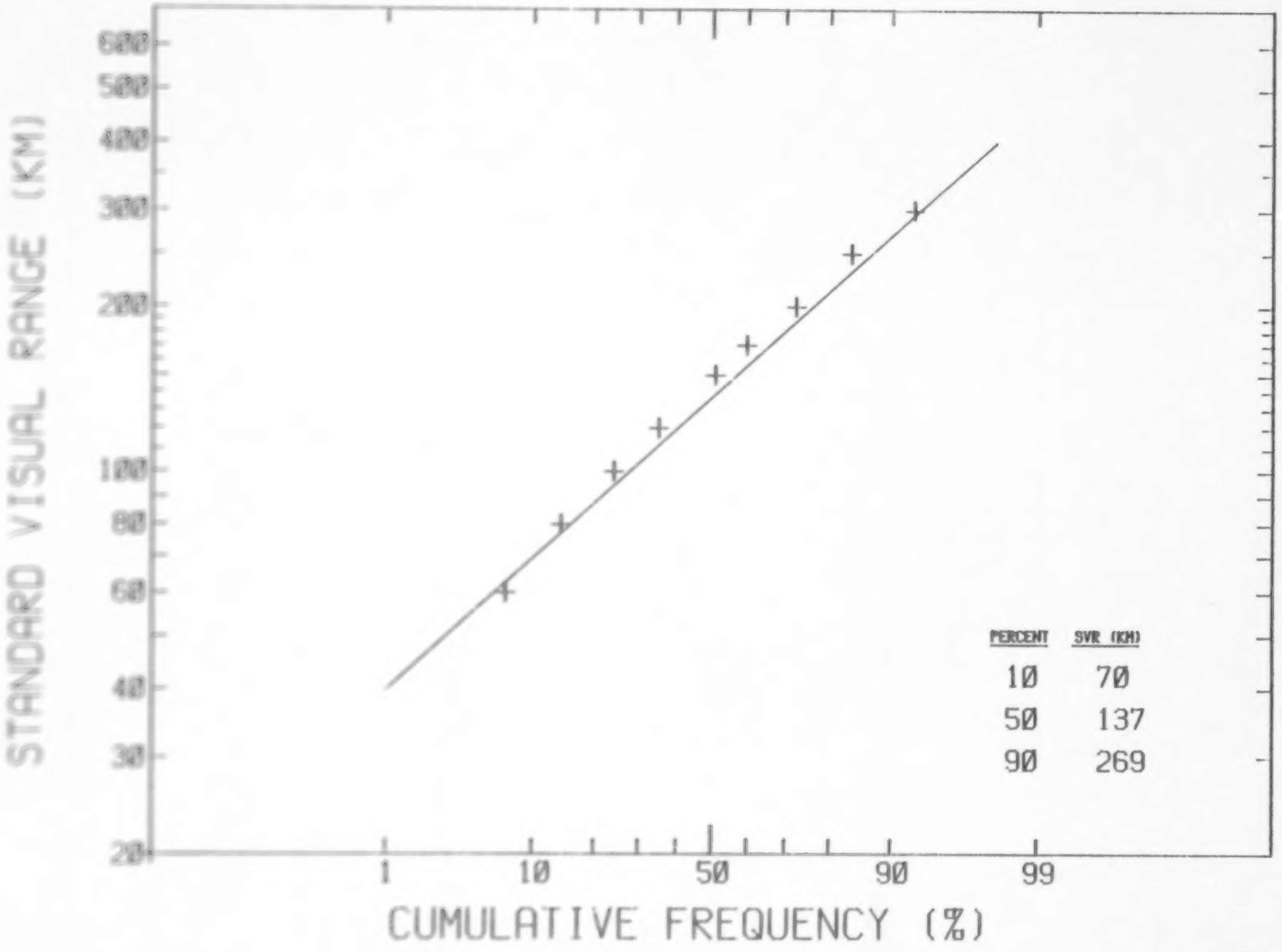


82/03/10.

WIND CAVE NATIONAL PARK

FROM MAY 79 TO SEP 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE



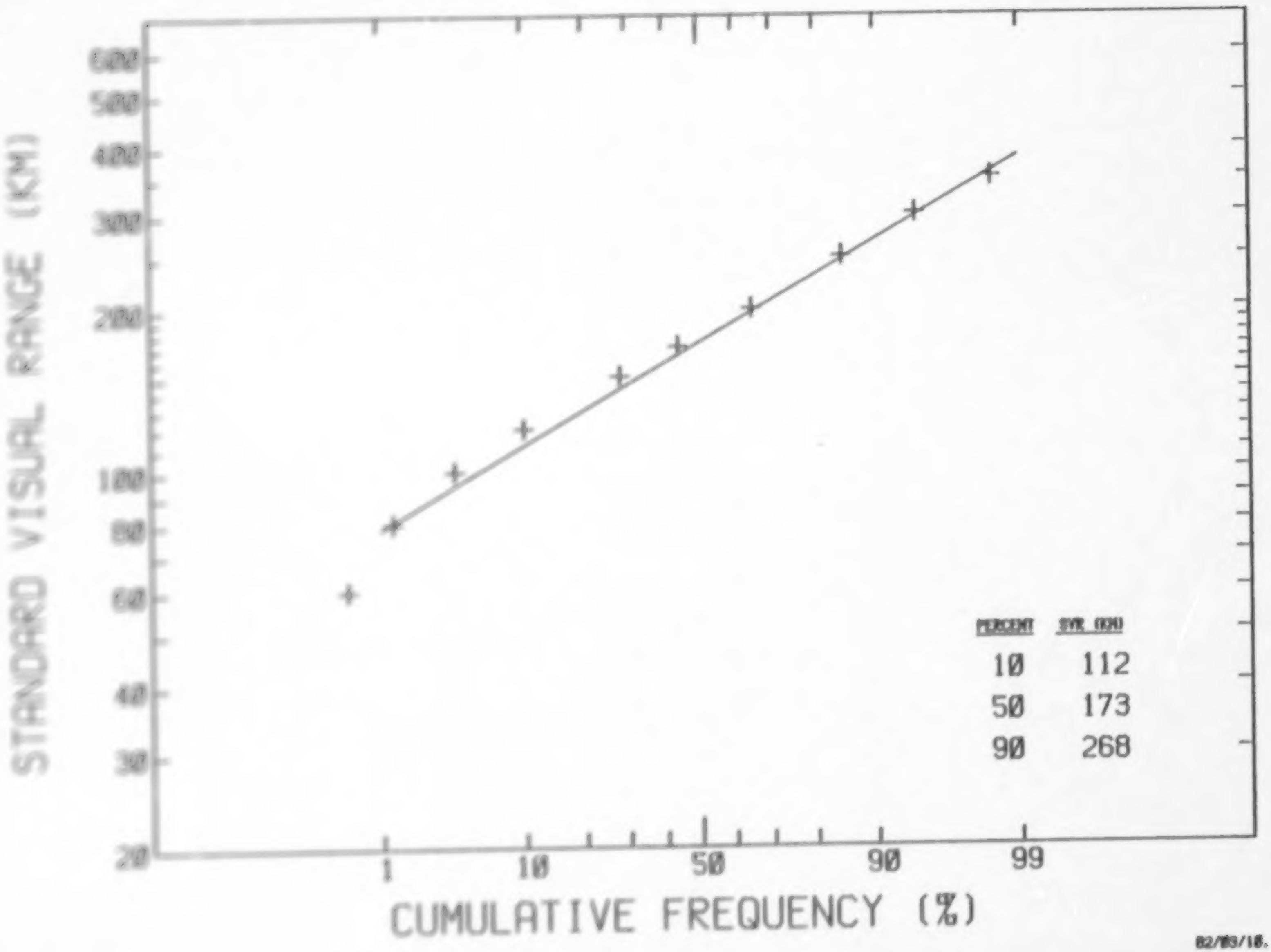
PERCENT	SVR (KM)
10	70
50	137
90	269

82/03/10.

COLORADO NATIONAL MONUMENT

FROM JUN 80 TO NOV 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE



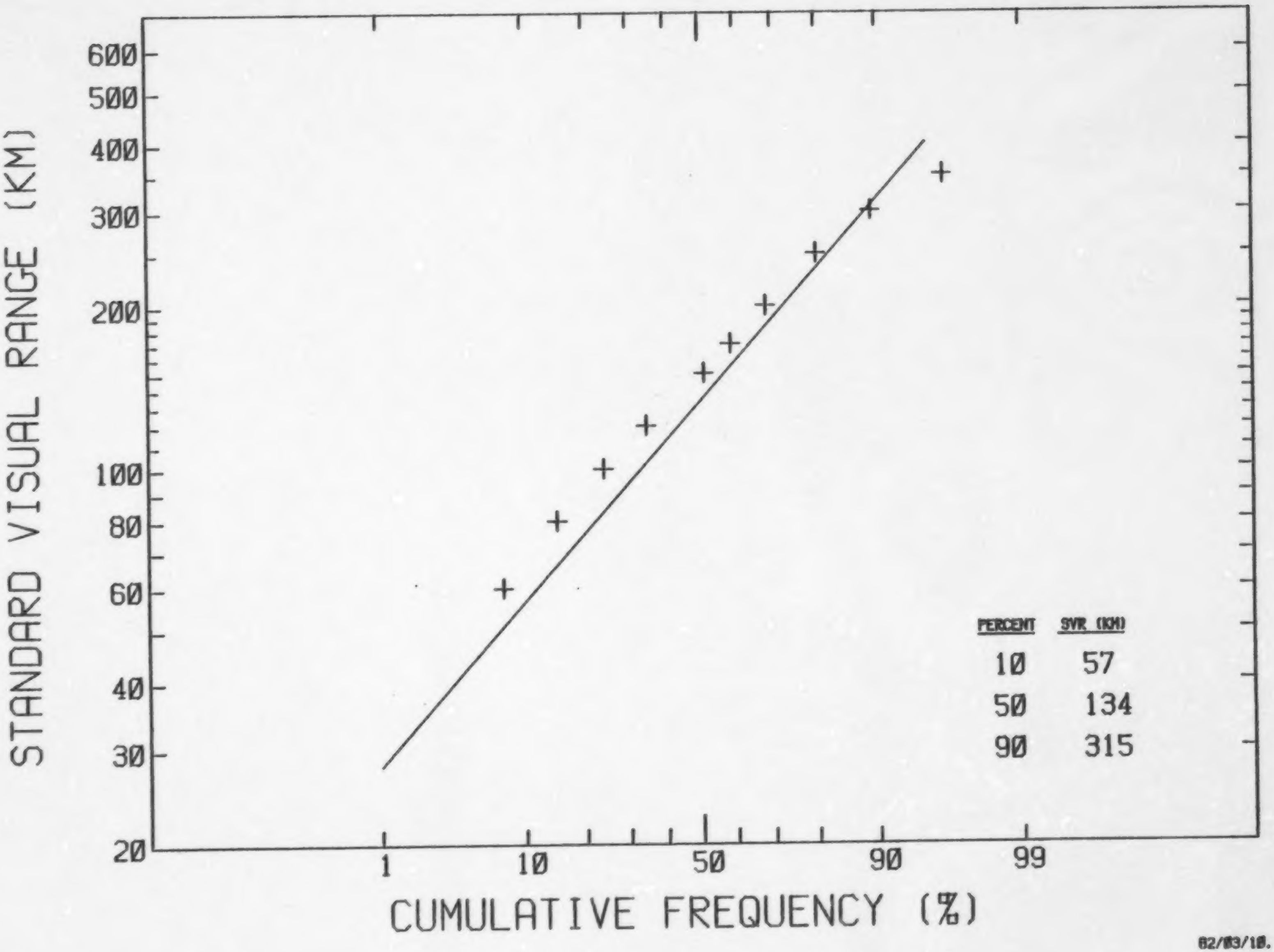
PERCENT	SVR (KM)
10	112
50	173
90	268

82/03/18.

ROCKY MT. NATIONAL PARK

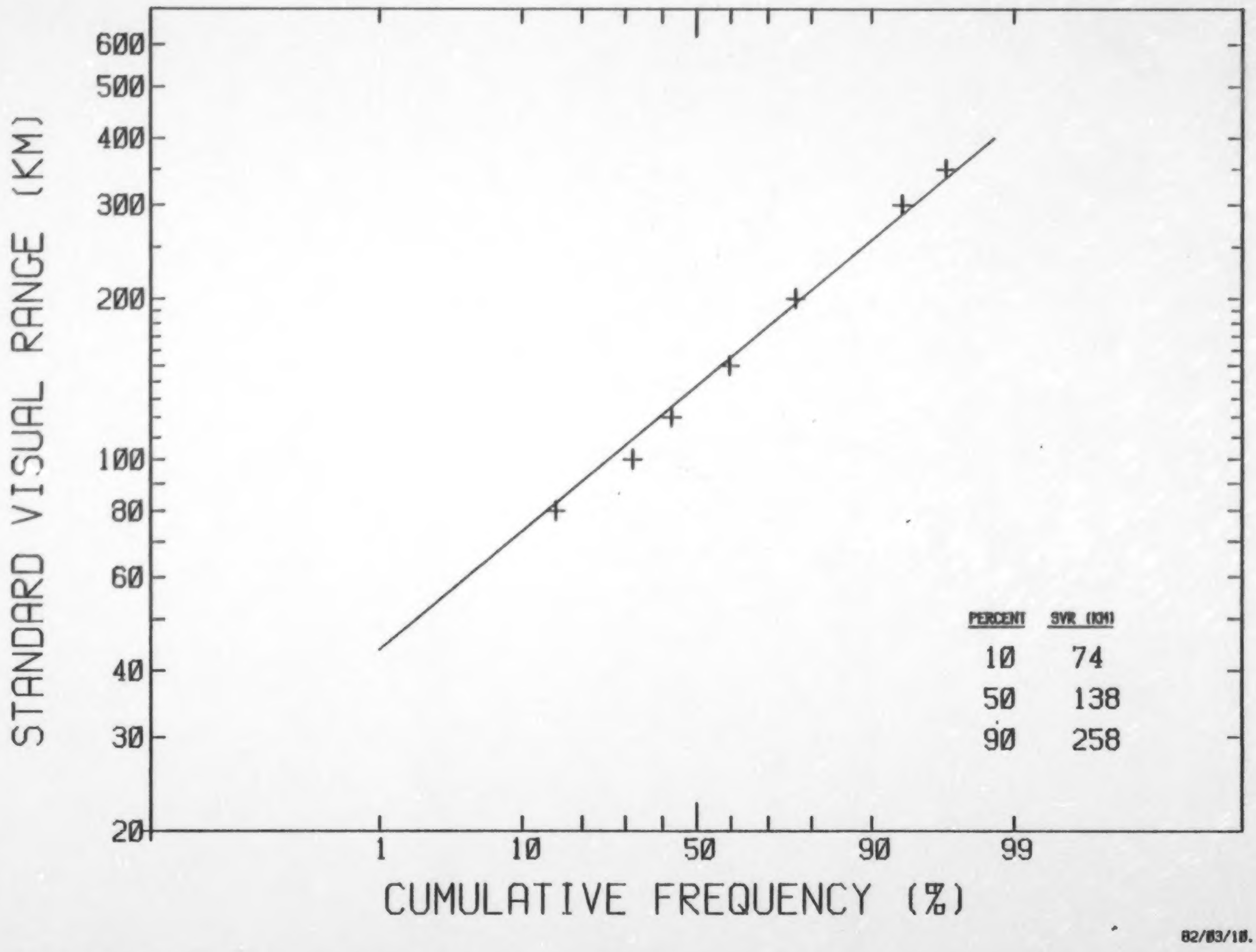
FROM JUN 80 TO NOV 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE



82/03/10.

CHIRICAHUA NATIONAL MONUMENT
FROM JUN 81 TO NOV 81
CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE

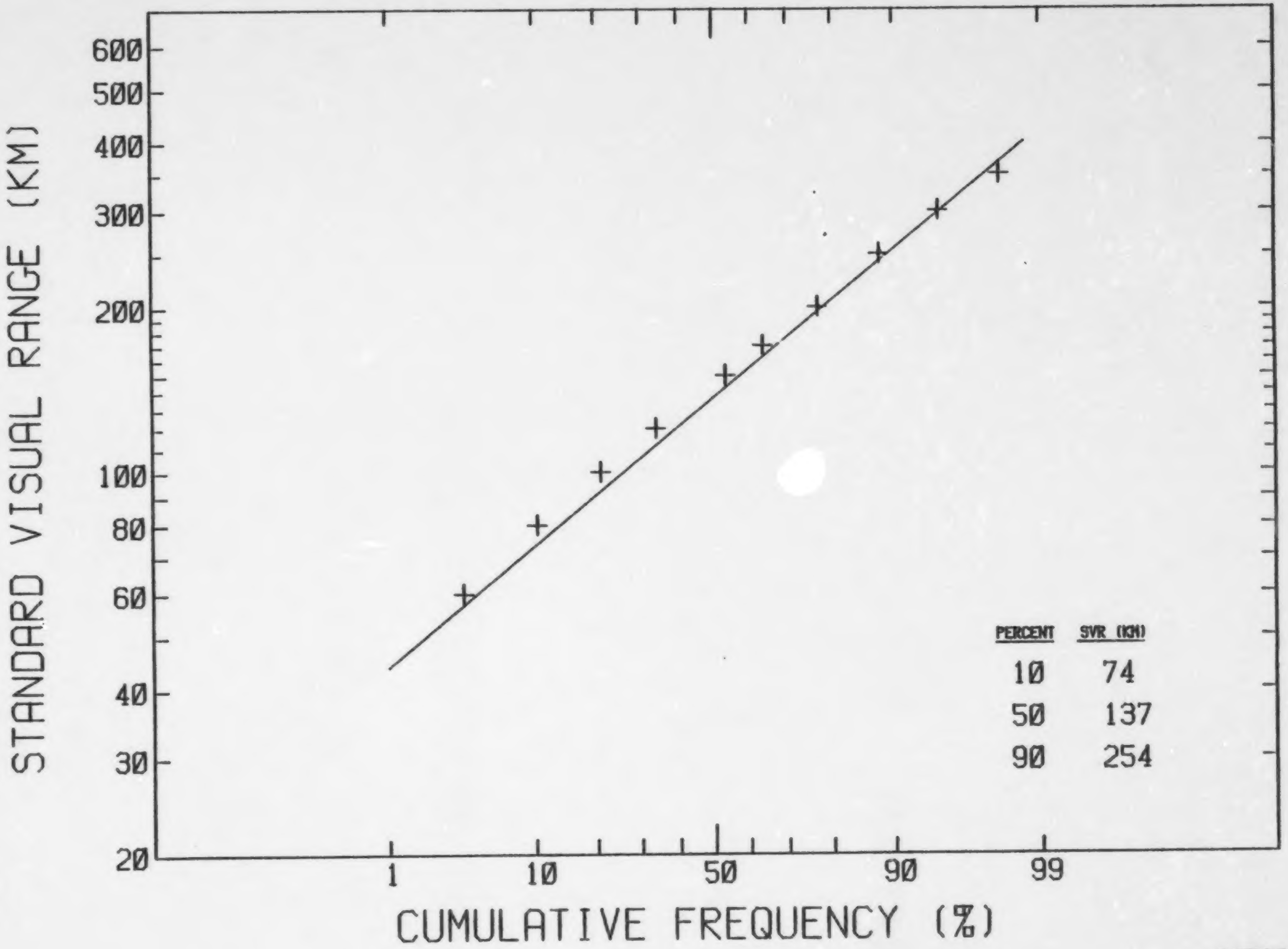


82/03/18.

GRAND TETON NATIONAL PARK

FROM JUL 80 TO NOV 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE

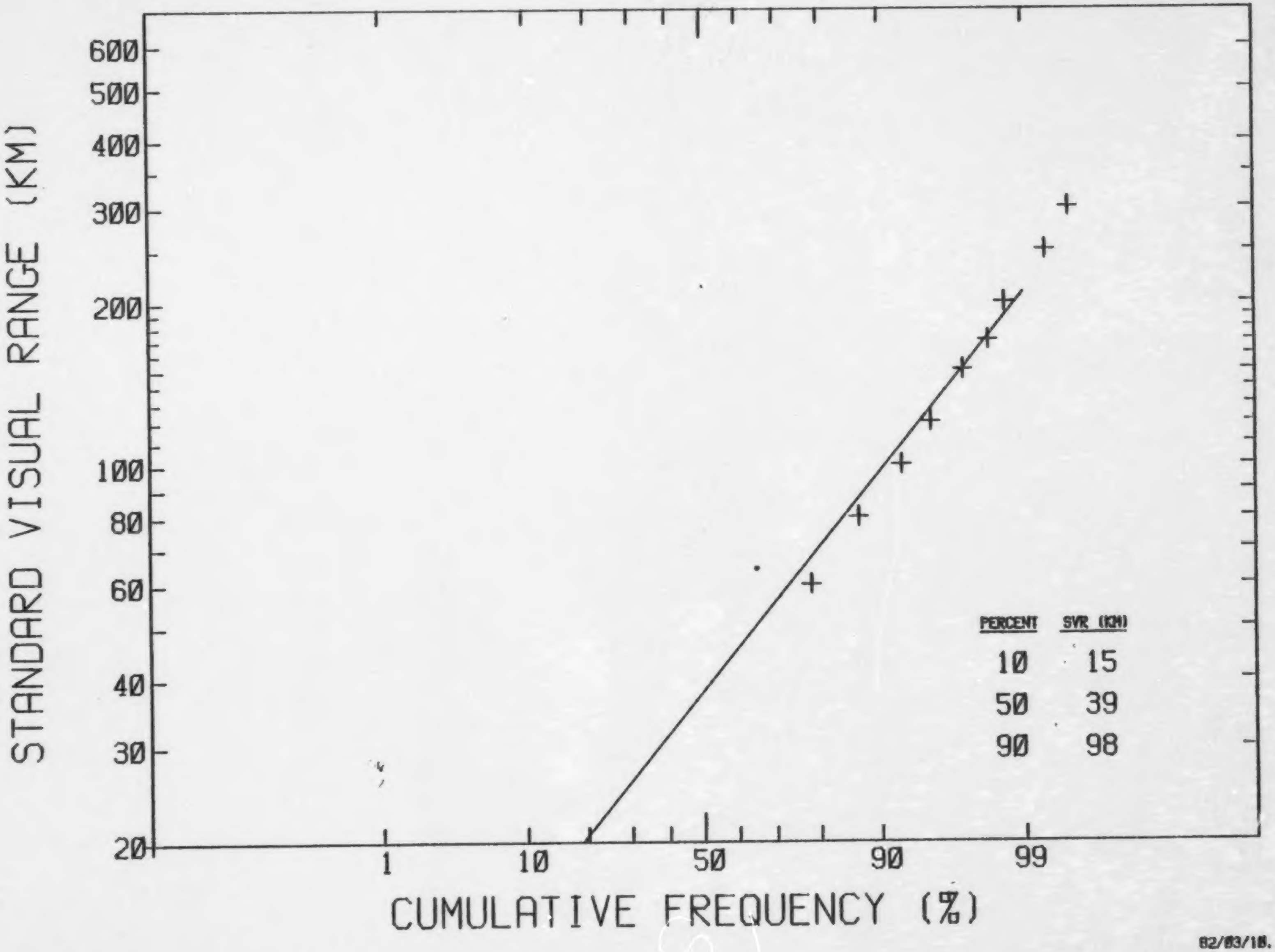


82/03/10.

SHENANDOAH NATIONAL PARK

FROM MAY 80 TO OCT 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE



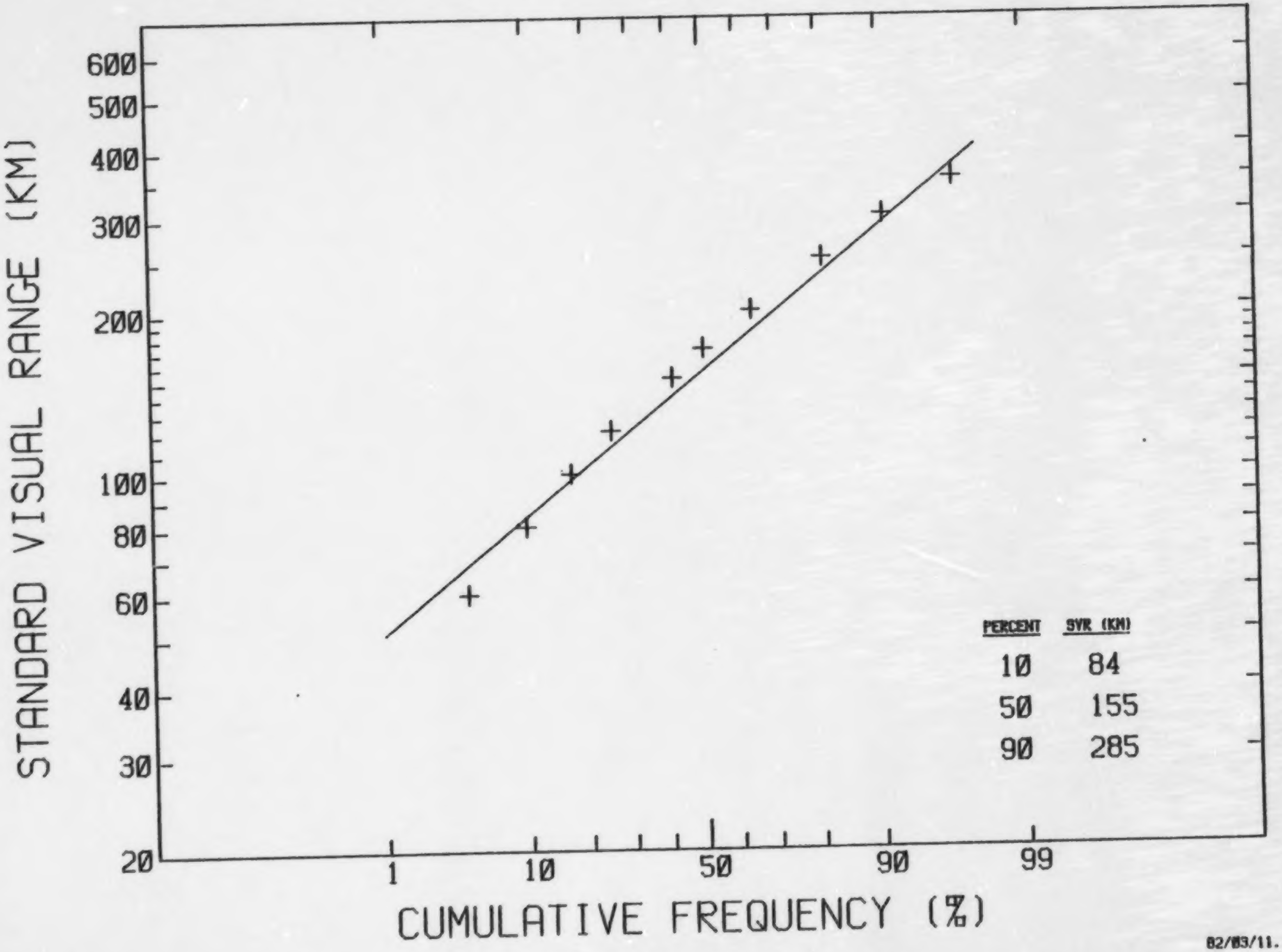
PERCENT	SVR (KM)
10	15
50	39
90	98

82/03/18.

CAPULIN MOUNTAIN NATIONAL MONUMENT

FROM APR 80 TO NOV 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE

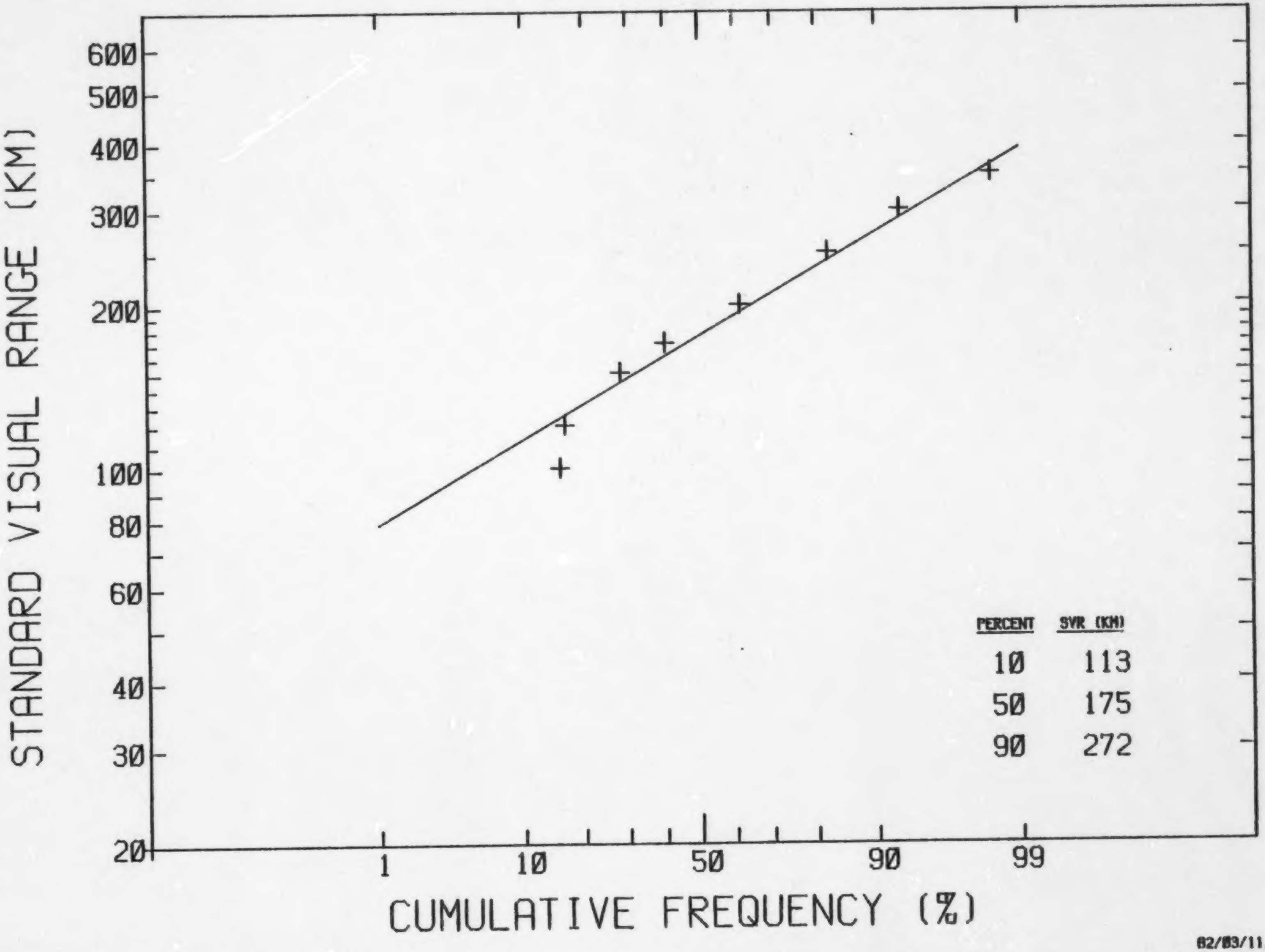


82/03/11.

TARGET 6 CHACO CANYON NATIONAL CULTURAL PARK

FROM NOV 78 TO NOV 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE

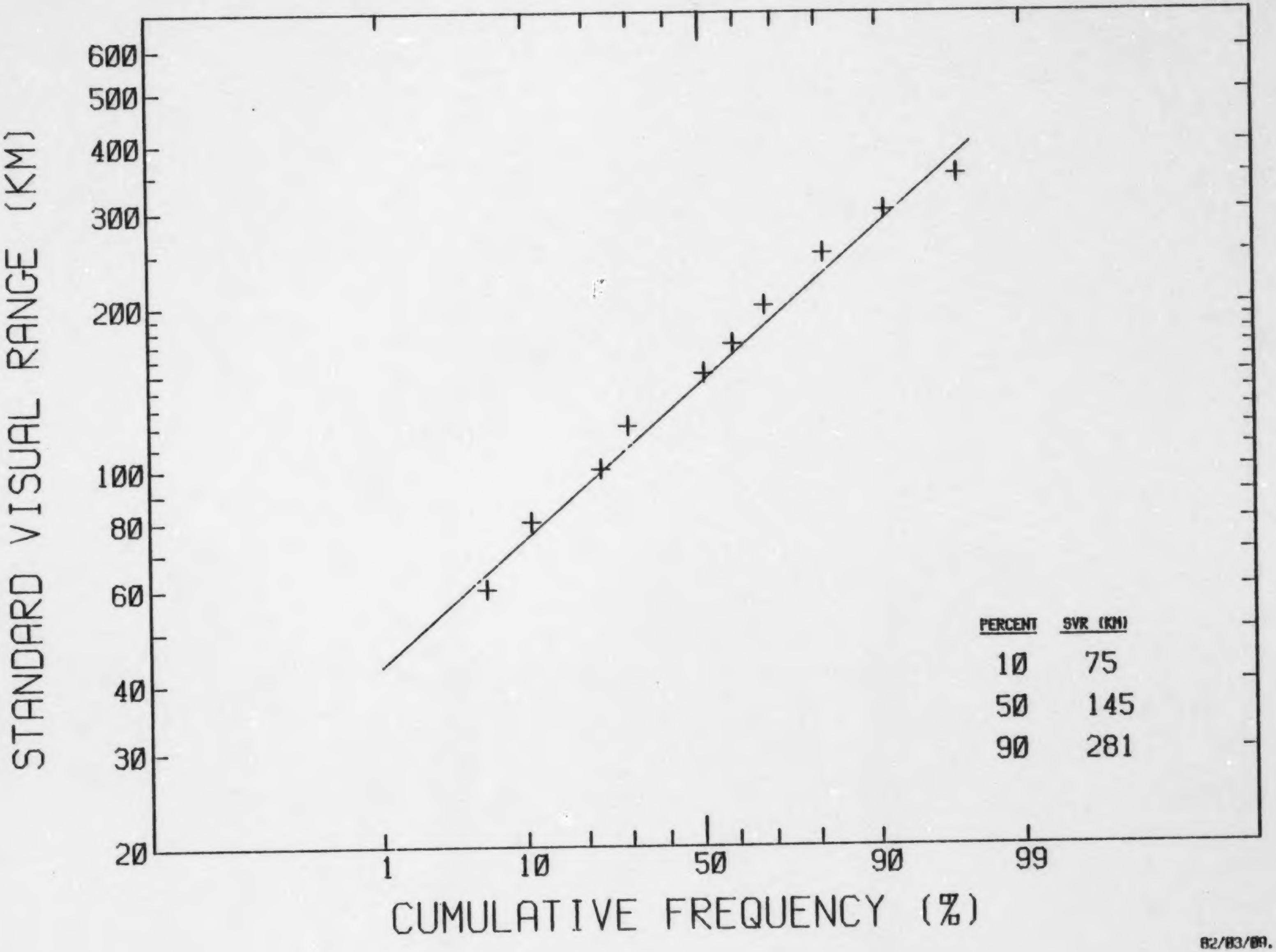


82/03/11.

DEATH VALLEY NATIONAL MONUMENT

FROM FEB 80 TO NOV 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE



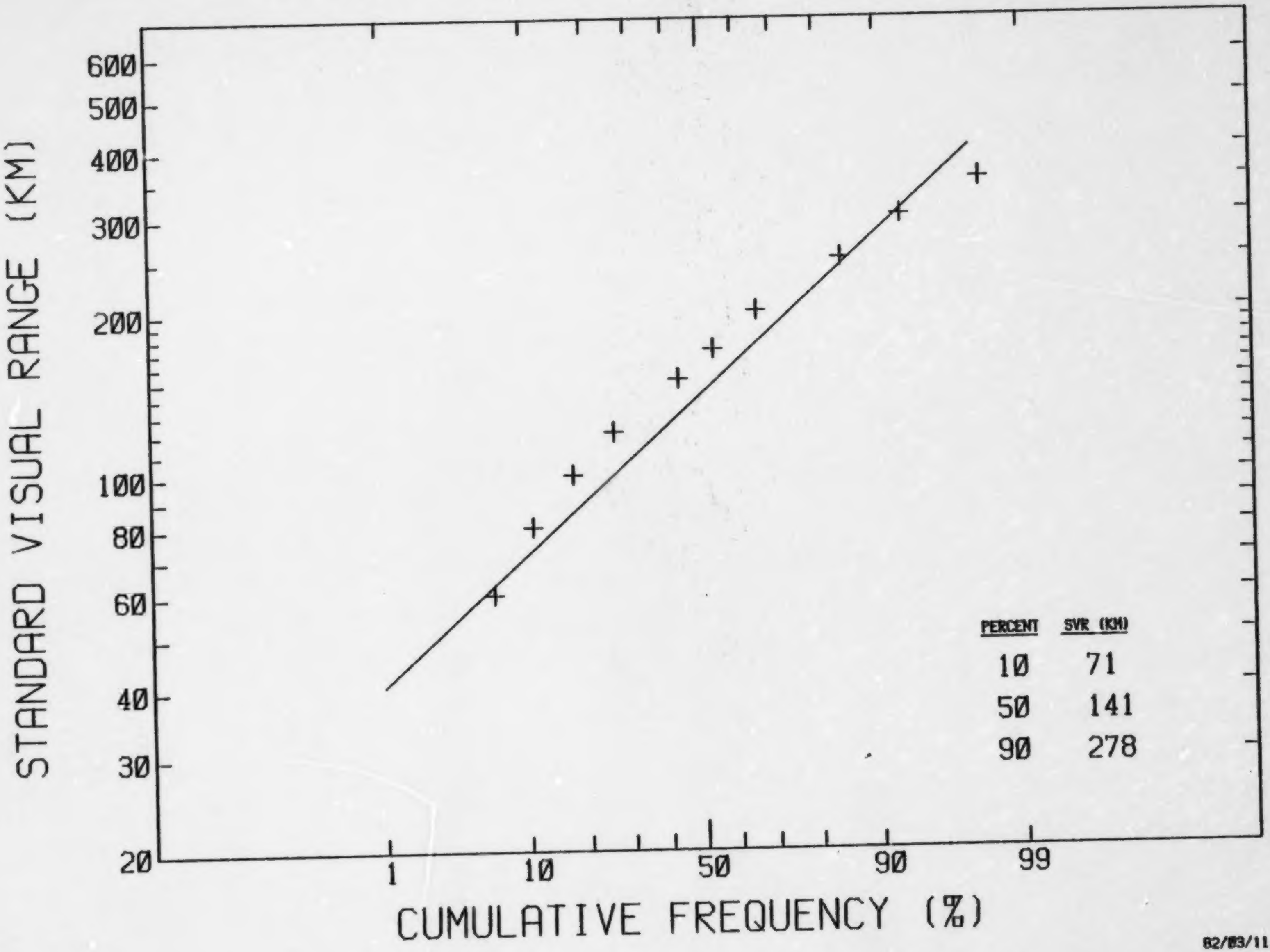
PERCENT	SVR (KM)
10	75
50	145
90	281

82/03/09.

YELLOWSTONE NATIONAL PARK

FROM JUN 81 TO NOV 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE

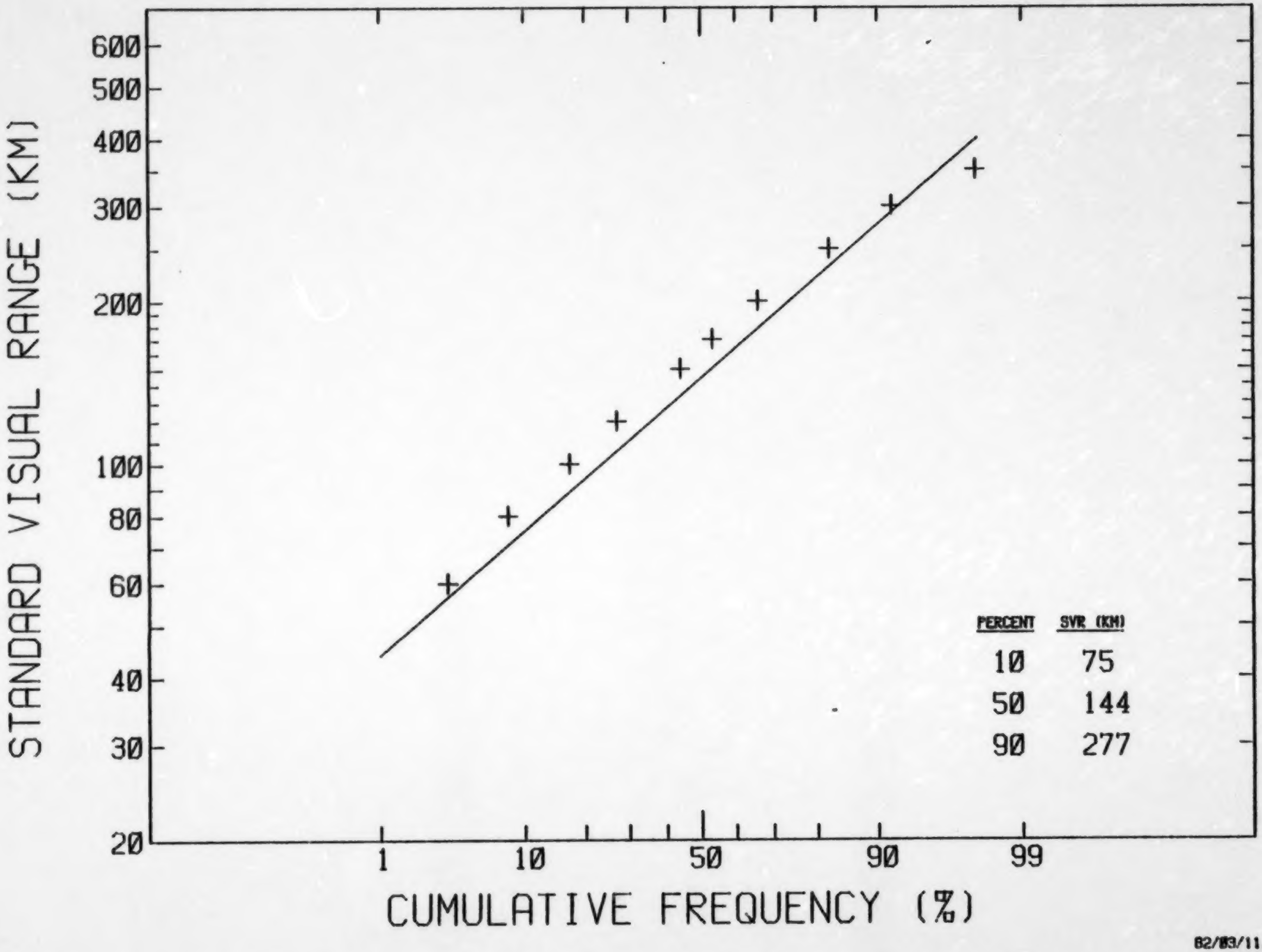


82/03/11.

TAHOE HIGH

FROM JUN 81 TO NOV 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE

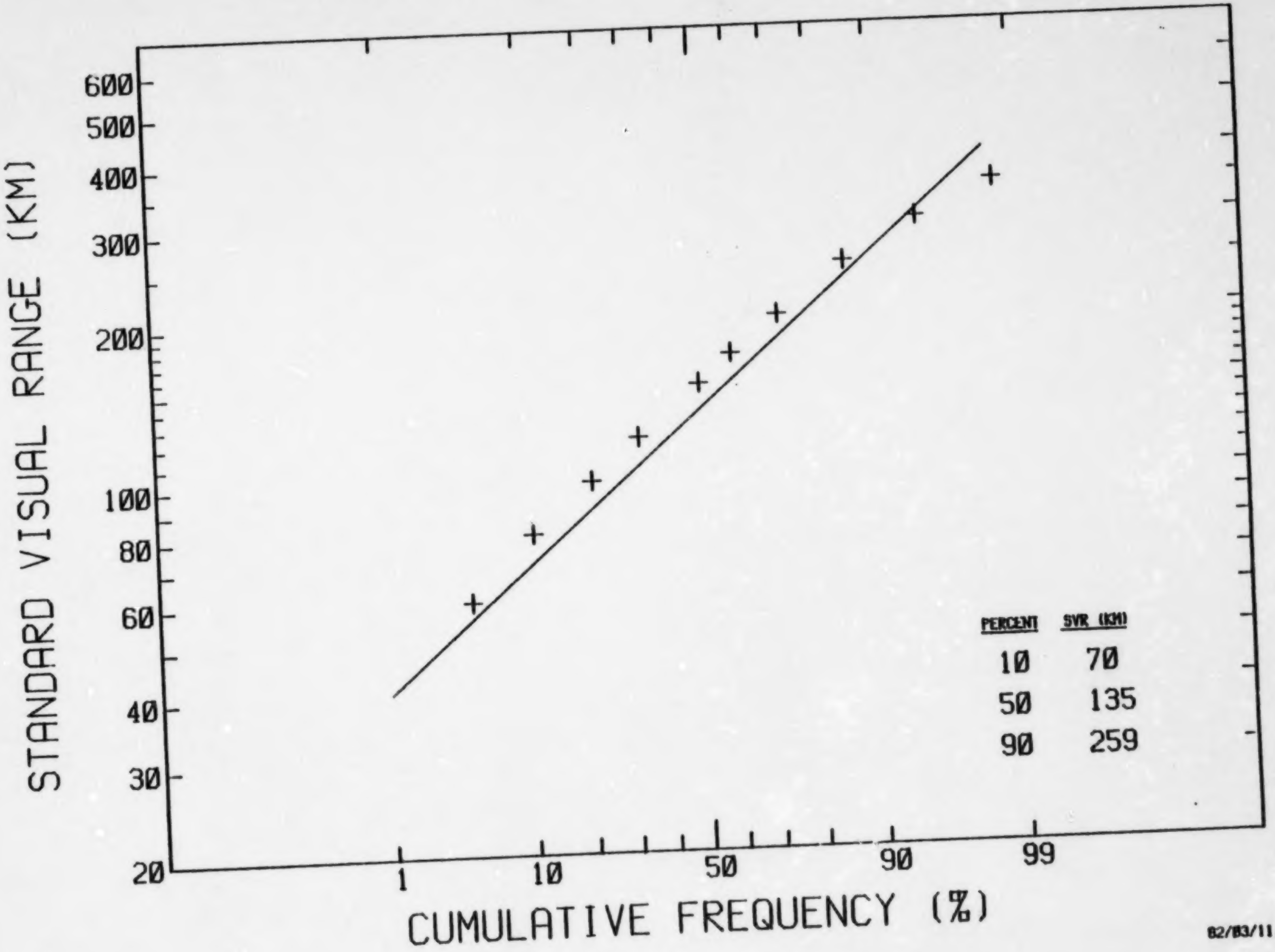


82/03/11.

TAHOE LOW

FROM JUN 81 TO NOV 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE

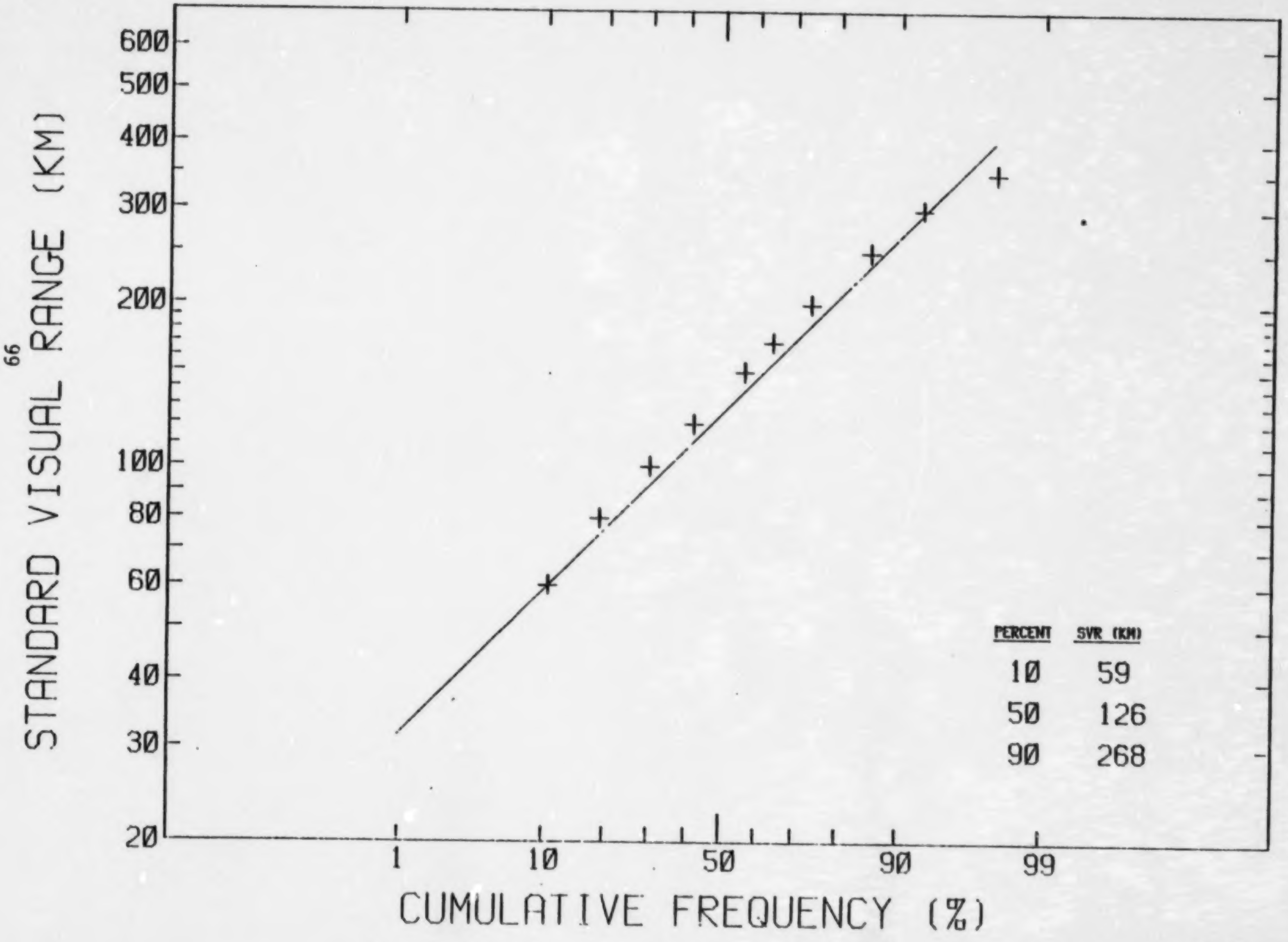


82/03/11.

BIG BEND NATIONAL PARK

FROM AUG 78 TO NOV 81

CUMULATIVE FREQUENCY OF STANDARD VISUAL RANGE



82/03/10.